



THE UNIVERSITY LIBRARY

PROTECTION OF AUTHOR'S COPYRIGHT

This copy has been supplied by the Library of the University of Otago on the understanding that the following conditions will be observed:

1. To comply with s56 of the Copyright Act 1994 [NZ], this thesis copy must only be used for the purposes of research or private study.
2. The author's permission must be obtained before any material in the thesis is reproduced, unless such reproduction falls within the fair dealing guidelines of the Copyright Act 1994. Due acknowledgement must be made to the author in any citation.
3. No further copies may be made without the permission of the Librarian of the University of Otago.

**GEOLOGY
OF TAKITIMU GROUP ROCKS
IN THE
NUGGET HILL REGION,
WESTERN SOUTHLAND,
NEW ZEALAND**

SAMANTHA MACCULLOCH

1992

Thesis submitted as partial requirement
for a Bachelor of Science (Honours) degree
in Geology at the University of Otago,
Dunedin, New Zealand.



Frontispiece 1: Photograph of me looking westward at the daunting task which lies ahead. (Photo taken by M. Moss at G.R. 165763).



Frontispiece 2: A photograph of the view from Rock Hut (G.R. 129733), of Heartbreak Spur (top left), on one of the cooler days.

ABSTRACT

An area approximately 31 km², centered around Nugget Hill in western Southland was mapped in detail. The geology in this area is dominated by Takitimu Group lithologies which are intruded by the White Hill Intrusive Suite. To the northeast of Nugget Hill, Barretts Formation unconformably overlies Takitimu Group and the White Hill Intrusive rocks. The Barretts Formation has been overthrust by the Murihiku Supergroup along the Letham Ridge Thrust. A sliver of Wairaki Melange occurs between the Barretts Formation and the Murihiku Supergroup.

The Takitimu Group consists of volcanic and volcanoclastic lithologies which were deposited in sedimentary basins flanking the volcanoes of an island arc system. The Group in the Nugget Hill area is divided in to two formations, the Heartbreak Formation consisting primarily of volcanic rocks with rare volcanoclastic material and the MacLean Peaks Formation which is dominated by intercalated volcanoclastic rudites, arenites and lutites with the occasional flow of basalt and basaltic-andesite lavas. The White Hill Intrusive Suite includes gabbros and microgabbros of very similar compositions to the Takitimu Group. Barretts Formation conglomerates and sandstones contain exotic clasts with respect to the Takitimu Group. These include granites, siliceous volcanics and ignimbrite.

A newly recognised southeastward plunging asymmetrical anticline has deformed the Takitimu Group in the region. The Telford Fault which strikes approximately north-west separates approximately east-west striking, south facing units from north-west striking, east facing units of the Takitimu Group. About 1 km of ^{displacement} ~~offset~~ is inferred at the south end and about 7 km of ^{displacement} ~~offset~~ is inferred at the north end of the fault. Southeast of Nugget Hill a southeastward dipping thrust fault is mapped and an oblique fault is mapped down the Wairaki River south of the Telford Burn confluence. These are splayed faults which accommodate offset at the southern end of the Telford Fault.

ACKNOWLEDGEMENTS

This thesis would not have come about without the help of the majority of the geology department at the University of Otago. Firstly I would like to thank my supervisor Associate Professor C. A. Landis, for his help in the field, his knowledge and useful discussions. I appreciate his great enthusiasm for my interesting discoveries. I would also like to thank my other three field assistants, Stuart Owen, Michael Moss and Ellen Maidens, for their enthusiasm, interest and time.

I am grateful to Mr and Mrs Alistair McGregor of Mt Linton Station, for allowing myself and my various field assistants to stay in their fabulous Rock Hut on and off while out in the 'field'. Mr Struan and Mrs Lyn Minty of Beaumont Station, must also be thanked for their wonderfully warm hospitality in allowing me to stay in their other house, use their Landrover, 4-wheeler and motorbike while doing fieldwork. Thanks also to Gillian Salton and Brian McAdoo for the use of their cars to, from, and in the field.

Laboratory investigations were much simplified by the help of many of the geology department staff. I would like to thank John Pillidge for advise in the thin-section lab, Roy Johnstone for technical assistance with XRF and XRD analyses, Don Weston for his photographic expertise, Dr Yosuke Kawachi in helping me to understand how to use the probe, Dr John Williams for help in hiring vans, Associate Professor Allan Cooper for his petrographical knowledge, Robin Cooper in obtaining aerial photographs and sending parcels, Emeritus Professor Doug Coombs for making zeolite identification a 'breeze' and Associate Professor Doug Campbell who was encouraging with the fossils and helped in proof reading.

Thanks to Damian Walls for his help with all computer problems, Nick Powell for the many times he proof read several chapters, Stuart Owen again for proof reading and comments, Adrian Dever and Lorraine Paterson for formatting and printing, Dr's Hamish Campbell for supplying fossil locality information and Bruce Houghton for briefly discussing "business".

Minor help, tips, discussions and suggestions were also given by all of the fourth years at some time or another, thanks also to Rupert Sutherland for a critical piece of geology, and Helen Abel for colouring in maps.

TABLE OF CONTENTS

FRONTISPIECE 1& 2.....	ii
ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iv
 Chapter 1.	
INTRODUCTION.....	1
LOCATION.....	1
REGIONAL GEOLOGY.....	1
WORLD CORRELATIONS.....	2
TOPOGRAPHY.....	3
BASIC STRATIGRAPHY.....	3
PREVIOUS WORK.....	5
AIMS OF THIS THESIS.....	7
 Chapter 2.	
TAKITIMU GROUP.....	10
INTRODUCTION.....	10
DISCUSSION & DESCRIPTION.....	10
Heartbreak Formation.....	11
MacLean Peaks Formation.....	12
VOLCANIC LITHOLOGIES.....	14
INTRODUCTION.....	14
VOLCANIC PETROGRAPHY.....	14
Primary Mineralogy.....	14
Metamorphic Mineralogy.....	16
Alteration Products.....	16
BASALTIC-ANDESITES.....	18
Distribution and Field Description.....	18
Petrography.....	19
BASALTS.....	20
Distribution and Field Description.....	20
Petrography.....	21
VOLCANIC GEOCHEMISTRY.....	21
Major Elements.....	21
Trace Elements.....	26
DISCUSSION.....	28
VOLCANICLASTIC LITHOLOGIES.....	28
INTRODUCTION.....	28
LITHOLOGIES.....	29
SEDIMENTOLOGY.....	30
RUDITES.....	35
Rudite Sedimentology.....	35
Clast Composition.....	36
Rudite Textures.....	36
Discussion.....	38
ARENITES & LUTITES.....	39
Arenite & Lutite Sedimentology.....	39
The Classical Turbidite Model.....	40
Bouma Sequences.....	41
Discussion.....	42
Arenite Petrography and Modal Composition.....	42

TABLE OF CONTENTS

Arenite & Lutite Geochemistry	44
Major Elements	44
Trace Elements.....	47
TUFF.....	48
Field Description.....	48
DEPOSITIONAL ENVIRONMENT & PROVENANCE OF VOLCANICLASTICS.....	49
Fan Model	50
AGE OF THE TAKITIMU GROUP.....	50
FOSSIL LOCALITIES.....	50
ENVIRONMENT OF DEPOSITION FOR THE TAKITIMU GROUP...53	
 <u>Chapter 3.</u>	
WHITE HILL INTRUSIVE SUITE.....	54
INTRODUCTION.....	54
DISTRIBUTION AND FIELD DESCRIPTION.....	54
PETROGRAPHY.....	54
Primary Mineralogy.....	55
Metamorphic Mineralogy.....	58
Alteration Products.....	59
GEOCHEMISTRY.....	59
Major Elements	59
Trace Elements.....	66
LAYERED WHITE HILL INTRUSION.....	67
Field Description of the Layered Intrusion	67
Petrography.....	68
Discussion.....	69
RELATIVE AGES OF THE WHITE HILL INTRUSIVE SUITE.....	69
POSSIBLE CORRELATIONS.....	70
 <u>Chapter 4.</u>	
BARRETTS FORMATION.....	71
INTRODUCTION.....	71
LITHOLOGIES.....	71
DISTRIBUTION & DESCRIPTION	73
BARRETTS SANDSTONES.....	76
Modal Analyses & Petrography.....	76
Petrographic Description	77
BARRETTS CONGLOMERATES.....	79
AGE OF THE BARRETTS FORMATION.....	80
ENVIRONMENT OF DEPOSITION & PROVENANCE.....	81
 <u>Chapter 5.</u>	
METAMORPHISM & ALTERATION	82
INTRODUCTION.....	82
METAMORPHIC ZONES	82
INTERPRETATION OF METAMORPHIC MINERALS.....	87
DISCUSSION	90
 <u>Chapter 6.</u>	
QUATERNARY TO RECENT GEOLOGY.....	91
 <u>Chapter 7.</u>	
STRUCTURAL GEOLOGY.....	93
INTRODUCTION.....	93

TABLE OF CONTENTS

FOLDING	93
FAULTING.....	96
 <u>Chapter 8.</u>	
DISCUSSIONS & CONCLUSIONS	99
SUMMARY.....	99
TIMING OF FOLDING & TILTING.....	100
NEW ZEALAND CORRELATIONS	100
CORRELATIONS WITH GYMPIE & NEW CALEDONIA	101
SIMILARITIES.....	101
DISSIMILARITIES.....	102
 <u>Chapter 9.</u>	
GEOLOGICAL SCENARIO	103
 REFERENCES CITED	107
 <u>Appendix A</u>	
PETROGRAPHIC NOTES & DESCRIPTIONS	111
Takitimu Group Volcanics.....	111
White Hill Intrusive Suite	112
Layered White Hill Intrusive.....	113
DETAILED DESCRIPTIONS	114
Takitimu Group Volcanic	114
White Hill Intrusive	115
 <u>Appendix B</u>	
XRF ANALYSES	117
 <u>Appendix C</u>	
MICROPROBE ANALYSES	122
 <u>Appendix D</u>	
NORMATIVE TABLES	131
Takitimu Group Volcanics.....	131
Takitimu Group Volcaniclastics.....	132
 <u>Appendix E</u>	
MODAL ANALYSES	135
Takitimu Group Arenites.....	135
Barretts Formation Sandstones.....	136
 <u>Appendix F</u>	
OPTICAL DISCRIPTIONS OF METAMORPHIC MINERALS	137
 <u>Appendix G</u>	
XRD ANALYSES	139
 <u>Appendix H</u>	
FOSSIL RECORD FORMS	144
 <u>Appendix I</u>	
GEOLOGICAL MAP OF THE NUGGET HILL REGION	

Chapter 1.

INTRODUCTION

LOCATION

The mapped area (NZMS 260, sheet D44) is located at the southern end of the Takitimu Mountains, and is centered around Nugget Hill, on Mt Linton Station (owned by Mr & Mrs Alistair McGregor), in Western Southland, New Zealand. The area covered is 31 km², about 5 km N-S by 6 km E-W, and is all on farmland. During the month of field mapping I stayed in Rock Hut which is located in the southwestern most corner of the area. The far eastern side of the area belongs to Beaumont Station (owned by Mr & Mrs Struan Minty).

Access to Rock Hut is via a reasonably good farm road from the McGregor homestead. An average car can be used in dry weather but a four-wheel drive vehicle is essential in the wet. A four-wheel drive track which goes in a loop around Nugget Hill makes walking to the boundaries much easier.

Access is also available from the Beaumont side via a farm road, although unfortunately there is no gate through the Beaumont/Mt Linton boundary fence, hence further access must be on foot.

The elevation of Nugget Hill is 675 m a.s.l., Rock Hut is situated at 340 m a.s.l., hence local relief is around 335 m. The Wairaki River flows from about 380 m in the top NE corner of the area to 320 m in the SW corner, over a distance of about 6 km, hence has a gradient of 0.57°. After heavy rainfall the Wairaki River may become very full very rapidly, hence making crossing it difficult. A foot bridge which crosses the river just below Rock Hut is very handy in times of flood. However it can only give access to the 1 km west of both the Telford Burn and the Wairaki River. Fords can be used across the Phoenix Gully Stream (D44/134743), the Parallel Stream (D44/164775) and the Wairaki River, north of the Parallel Stream (D44/1595779) (Map).

REGIONAL GEOLOGY

The South Island of New Zealand is divided into two distinct provinces, the Eastern and Western (Figure 1.1), by a Median Tectonic Line (Landis & Coombs 1967). The Eastern Province consists of 8 tectonostratigraphic terranes. The Brook Street Terrane in New Zealand is extensive in the South Island. It can be recognised near Bluff on the South Coast (Wood, 1959), in the Takitimu Mountains northwest of Bluff (Mutch, 1972), in the Dunton Range between the Eglinton Valley and the Takitimu Mountains (Grindley, 1958; Lindsay, 1980;

Turnbull, 1986). They are also found in the upper Eglinton Valley along the eastern margin of Fiordland (Williams, 1978), in the Skippers range of northwest Otago (Ballard, 1989), to the northwest of Nelson City (Johnston, 1980) and near Lake Rotoiti (Johnston 1990). The northernmost occurrence of the Brook Street is on D'Urville Island in Cook Strait (Sivell & Rankin, 1983). The Takitimu Group occurs in the Takitimu Mountains in western Southland.

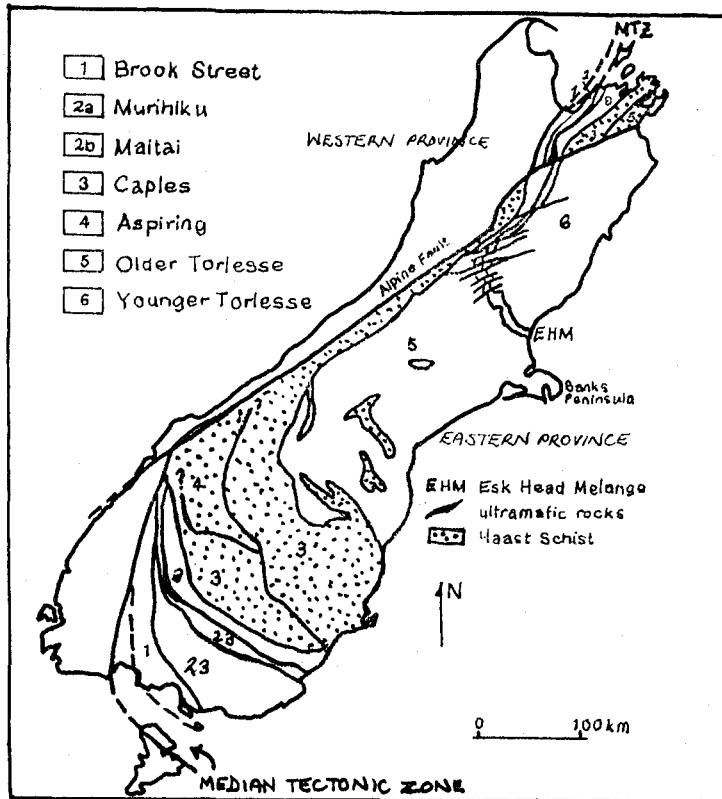


Figure 1.1 Generalised tectonostratigraphic terrane map of the Eastern Provinces in the South Island of New Zealand (modified after Frost & Coombs, 1989).

The bulk of the Takitimu Mountains, in Western Southland, is made up of Lower Permian interbedded marine volcanoclastic sediments and basaltic to rhyodacitic volcanic rocks of the Takitimu Group. This study concentrates mainly on the Takitimu Group rocks, specifically the Heartbreak Formation and MacLean Peaks Formation (Houghton, 1977). In general the Takitimu Group rocks across this whole region are thought to be about 14 km thick and structurally subvertical (Houghton, 1977). A large fault zone separates the Takitimu Group, on the west, from sediments in the Waiau Basin (Bowen, 1964). Gabbroic and microgabbroic intrusions within, and closely associated with the Takitimu Group are incorporated into the White Hill Intrusive Suite. Along the Wairaki Hills on the eastern side of the Takitimu Ranges (Figure 1.2), Takitimu Group rocks are unconformably overlain by gentle northeastward dipping, Jurassic conglomerates and sandstones of the Barretts

Formation. These rocks are also included in this study. The Barretts Formation is fault bounded, on the east by Triassic Murihiku Supergroup rocks of the southwestern limb of the Southland Syncline. The nature of the relationship between the Murihiku Supergroup and the Brook Street Supergroup is not clear. It is not certain whether the Murihiku Supergroup is allochthonous with respect to the Brook Street Supergroup (Frost & Coombs, 1989; Haston et. al., 1989) or whether the Brook Street Supergroup was in the vicinity of the Murihiku arc during the Jurassic (Aslund, 1988 & 1989; Powell, 1992).

WORLD CORRELATIONS

Geologists working in the Brook Street Supergroup in New Zealand have been able to correlate lithologies with similar lithological groups in other parts of the world. Waterhouse & Sivell (1987) put forward a valid case study for the correlation of the Takitimu Group with the Gympie Group in southeast Queensland and New Caledonia. Together with rocks in New Zealand (Nelson-Eglinton-Takitimu) and the western side of New Caledonia (Waterhouse 1970 in Waterhouse & Sivell, 1987), the Gympie rocks are thought to comprise the remnants of a magmatic arc-mobile belt that extended along the margin of Gondwana.

Volcanics of the Gympie Group comprise mainly marine basaltic pyroclastic rocks together with subordinate lava flows and dykes. Massive, poorly-sorted amygdaloidal basaltic to basaltic-andesite tuff-breccias predominate. Other lithologies include amygdaloidal basaltic agglomerate, primary and redeposited ash-fall tuffs, and minor flows of spilitic lavas, as well as volcanoclastic arenites, turbidites and volcanogenic rudites. Stratigraphically higher lithologies in the Gympie Group include more felsic shales, silicified argillites, feldspathic greywackes and volcanic conglomerates.

Lithological and geochemical relations described from the Gympie Group are consistent with dominantly calc-alkaline arc development. The same volcanic chain appears to be present in West New Caledonia (Avias, 1953; Waterhouse, 1956, 1967; Guérange et. al. 1975 in Waterhouse & Sivell, 1987). Fine tuffs, augite porphyries and basalt to basaltic-andesite submarine flows are present. Some dacite and rhyolitic tuffs have also been reported (Paris & Lillie, 1977 in Waterhouse & Sivell, 1987).

In the Gympie Group there are no marine Triassic sediments or faunas like the well developed richly fossiliferous marine Triassic sediments of the Murihiku Supergroup in New Zealand. In New Caledonia, Triassic sediments are richly fossiliferous and very similar faunally to those of New Zealand (Campbell et al. 1985 in Waterhouse & Sivell 1987), but differ in that they contain a much more substantial terrestrial component, with impure coal measures (Paris & Bradshaw, 1977 in Waterhouse & Sivell, 1987).

TOPOGRAPHY

The topography of the Nugget Hill region is important in that it is largely controlled by the underlying lithologies. The Takitimu Group in the west of the Nugget Hill region is subvertical giving rise to steep hill slopes and narrow ridges at altitudes of around 600 m. Nugget Hill itself consists primarily of subvertical volcanoclastic sediments. Interbedded sandstones, mudstones and coarse rudites form a striking pattern of prominent ridges (more resistant rudites) and hollows (arenites & lutites) trending in a NE-SW direction. In the far east of the area the topography becomes less rugged and tends to form low rolling hills, predominantly sandstones. Aerial photographs in this region show thin resistant beds of rudite very well. The east's low topography is also due to the presence of the more easily eroded Barretts Formation.

The Wairaki river cuts perpendicularly across strike of the Takitimu Group rocks in the north of the mapped area, turning towards the southwest near the Telford Burn intersection.

BASIC STRATIGRAPHY

Figure 1.2 is a representative stratigraphic column for the geology in the Nugget Hill area. The Early Permian Takitimu Group lithologies are included in the Heartbreak Formation (about 1 km thick) and the MacLean Peaks Formation (about 3 km thick). Volcanic and volcanoclastic lithologies dominate in the Heartbreak and MacLean Peaks Formation respectively.

The Takitimu Group is intruded by White Hill Intrusive gabbros and microgabbros throughout the sequence and in this region is deformed by strike-slip and reverse faulting and an anticline fold.

An angular unconformity cuts into the Takitimu Group in the northeast of the area, and is overlain by conglomerates and sandstones of the Jurassic Barretts Formation. Middle Triassic Murihiku Supergroup overthrusts the Barretts Formation along the Letham Ridge Thrust. A sliver of Wairaki

INTRODUCTION

Melange occurs between the Barretts Formation and Murihiku Supergroup.

Quaternary gravel terrace sequences have developed to the southwest of Nugget Hill on either side of the Telford Burn and the Wairaki River.

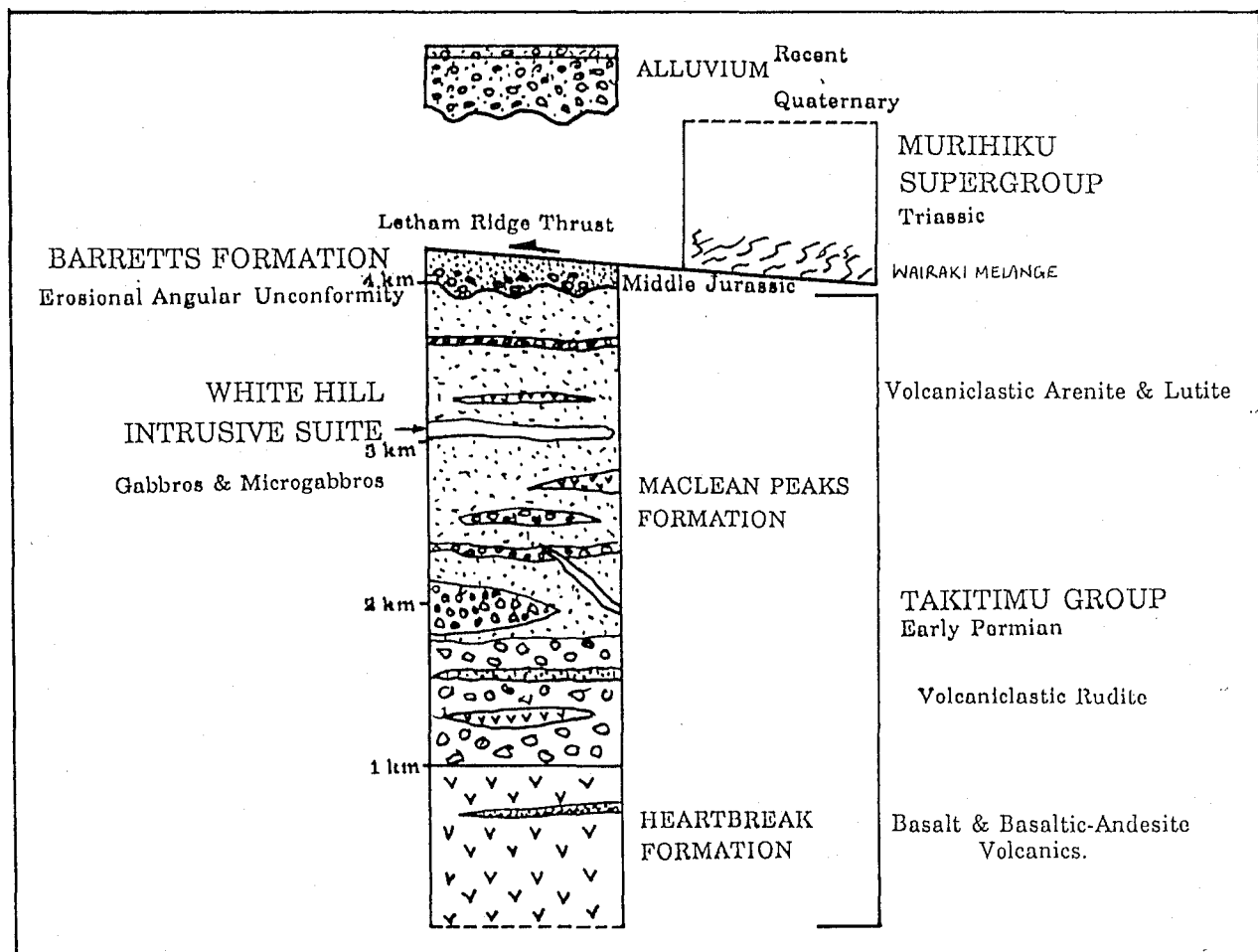


Figure 1.2. Generalised stratigraphic column for the Nugget Hill region.

PREVIOUS WORK

This region had not been previously mapped in detail. It has however had reconnaissance work done by Mutch (1972). Waterhouse (1967) proposed a biostratigraphical subdivision of the New Zealand Permian based in part, on a section through the Takitimu and Productus Creek Groups along the Wairaki River.

This region was first studied by J. T Thomson (1859), who reported on a reconnaissance survey of the southern districts of Otago. He noted that the Wairaki Hills consist of "stratified formations hardened by metamorphic action and much tilted up and broken." From various rock types in river gravels draining the mountains he deduced that the interior Takitimu Mountains were composed of granite and gneiss with porphyry, cherts, greenstone and amygdaloids."

The geology of the Southland District as a whole was reported by Hutton in 1872. On his map he indicated Takitimu rocks as being Late Paleozoic. He described their lithologies as phyllites with diorite dykes which were all dipping to the ESE and WNW alternately. He considered the Paleozoic rocks of the Takitimu Mountains and the Mesozoic rocks of the Wairaki Hills to form a NW-SE trending, SE plunging syncline and to be separated from each other by an unconformity.

Hutton and Ulrich (1875) indicated on their map that the Takitimu Mountains belonged to the Kaikoura Formation of late Paleozoic age. In 1878 Cox mapped the north end of the Takitimu Mountains as far south as the Aparima River. He described the Takitimu rocks as grey and green sandstones and slates, purple jasperoid slates, serpentinous shales and multicoloured compact slate breccias, intruded by contemporaneous veins and dykes of grey feldspathic syenite, in places highly hornblendic. The general dip was stated to be 70° ENE.

Park in 1910 classified the Takitimu rocks in the Te Anau System (Carboniferous) on the basis of work done in the northern Takitimu Mountains. In 1921 Park considered the rocks of the Takitimu Mountains and Wairaki Hills to be part of the Maitai System (Permo-Carboniferous). Park decided that the structure in the Takitimu mountains was a series of anticlines and synclines striking NW.

Rout and Willet (1949) gave the first detailed geological account of the Wairaki Hills, in which they discovered Permian fossils.

Mutch (pub. 1972, written 10 yrs earlier) described the Morley Subdivision which encompasses much of the Takitimu Mountains. He found many fossil localities in the Takitimu Group and was, for the first time, able to date lithologically similar groups. The type section for the group was defined as being the course of the Wairaki River from the Elbow Creek junction to MacKinnon's Garden near the junction of the Gibraltar Burn. Mutch described the Takitimu Group as a single homoclinal sequence of subvertical volcanigenic lithologies which young towards the east.

Waterhouse (1964) gives a detailed account of Permian stratigraphy and faunas in New Zealand and noted that it is only in the Takitimu region that fossils are present throughout the Lower Permian sequence. This area, hence provided a standard sequence for the older Permian in New Zealand.

Houghton (1977) mapped in detail the lithologies and structure of the Takitimu Group in the Central Takitimu Mountains (Figure 1.3). He has subsequently written papers on the lithostratigraphy (Houghton 1981), petrology (Houghton, 1985), intrusives (Houghton, 1986), sedimentation and volcanism (Houghton & Landis, 1989) of the Takitimu Group.

Landis (1987) has worked on Permian-Jurassic rocks at Productus Creek-Letham Ridge, Southland. He proposed recognition of the Barretts Formation for newly recognised granitic conglomerates and sandstones of Jurassic age and mapped a thrust contact between Takitimu and Barretts Formations, and structurally overlying Murihiku Supergroup to the east.

Aslund (1988) mapped Permian-Jurassic rocks in the Beaumont area, east of Nugget Hill and continued the thrust (Letham Ridge Thrust) relationship between Triassic rocks of the Murihiku Supergroup and the Barretts Formation into the Beaumont region (Figure 1.3).

Willsman (1990) mapped the Wether Hill area to the south of Nugget Hill and describes the nature of the boundary between the Takitimu Group and the Murihiku Supergroup and establishes the presence of the Barretts Formation and the Letham Ridge Thrust in the area (Figure 1.3).

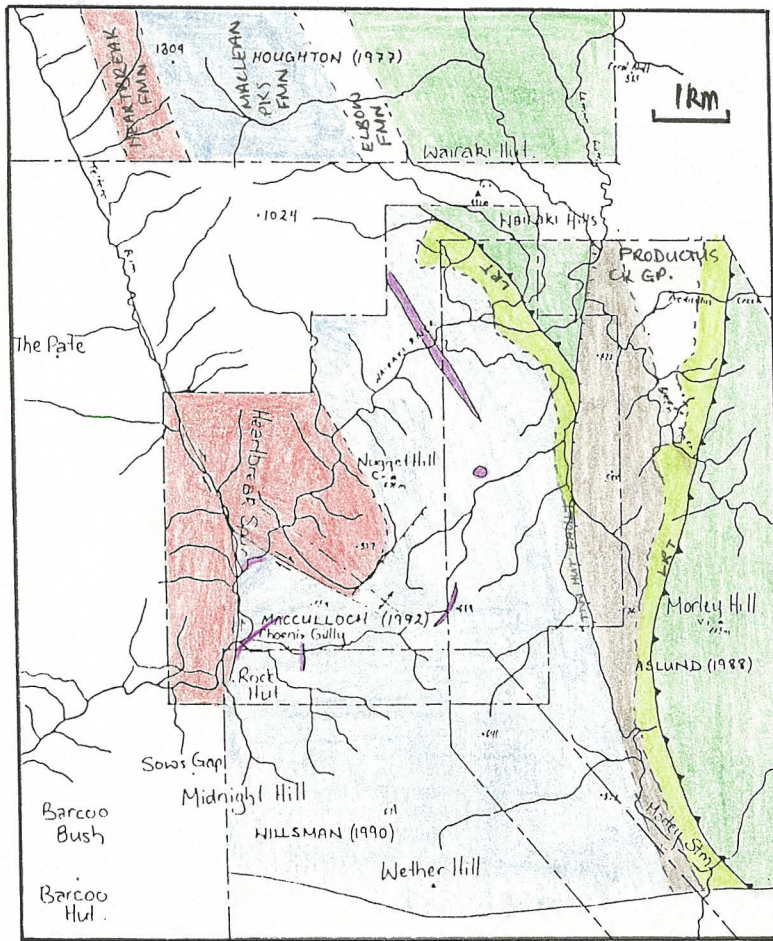


Figure 1.3. Location of the mapped area showing the surrounding areas mapped by previous workers, namely Houghton (1977), Aslund (1988) and Willsman (1990). Shown, also is the distribution of the various Formations and Groups within the region. (for legend see MAP)

AIMS OF THIS THESIS

This thesis is based on 28 days of mapping and subsequent laboratory investigations. The aims of this work are;

1. To produce a detailed map of rocks within the Takitimu Group and Barretts Formation in the Nugget Hill region which has not been mapped in detail previously.
2. To compare and explain compositions present within the Takitimu Group on the basis of petrography, geochemistry and distribution and in particular compare the geochemistry and petrography of Takitimu Group extrusives and White Hill Intrusive lithologies.

INTRODUCTION

3. To compare the structure and stratigraphy of Takitimu Group rocks at the southeastern end of the Takitimu Mountains with Takitimu Group rocks mapped by Houghton (1977) in the central Takitimu Mountains.

4. To map the distribution of metamorphic and alteration minerals in the area.

5. To compare the Takitimu Group lithologies in the Nugget Hill region with similar geological systems in other parts of New Zealand, Gympie, Australia and New Caledonia.

Chapter 2.

TAKITIMU GROUP

INTRODUCTION

The Takitimu Group of western Southland comprises an eastward younging, 14 km thick sequence of subvertical calcalkaline volcanic and volcanoclastic rocks (Houghton, 1977). It is locally intruded by microgabbros and microdiorites of the White Hill Intrusive suite. The Group forms the major part of the Takitimu Mountains and is fault-bounded on the western flanks against sediments of the Nightcaps Group (Mid-Eocene to Early Oligocene (Bowen, 1964)), which is part of the Waiau Basin sequence. On the eastern side the Takitimu Group is faulted against the Murihiku Supergroup and locally unconformably overlain by the Barretts Formation.

Houghton (1981) subdivided the Takitimu Group into five formations on the basis of lithostratigraphy. From the oldest (in the west) to the youngest (in the east) the formations and their content as published by Houghton include the;

Brunel Formation, comprising hemipelagic and distal basic volcanoclastic sediments with subordinate basaltic lava flows, hyaloclastites, and rare rhyodacitic lava flows.

Chimney Peaks Formation, comprising redeposited volcanoclastic arenites and subordinate rudites and basaltic and rhyodacitic rocks.

Heartbreak Formation, comprising of a succession of microgabbro and basaltic lava, pillow lava and breccia. It is distinctive because it contains little or no volcanoclastic sediment.

MacLean Peaks Formation, which is characterised by volcanoclastic arenites and rudites and submarine lava flows. Andesite first appears in this formation and there is a continuous range of silica content from basalt to andesite.

Elbow Formation, which contains abundant rudites, including clast supported conglomerates and arenites. Lavas range from basalt through to andesite.

DISCUSSION & DESCRIPTION

Much of the Nugget Hill region can be assigned to two of the above formations, namely the Heartbreak Formation and the MacLean Peaks Formation (see Map). The Elbow Formation mapped (Houghton, 1977) on the eastern edge of the Central Takitimu Mountains can not be recognised in the Nugget Hill area on the basis of lithology.

Heartbreak Formation

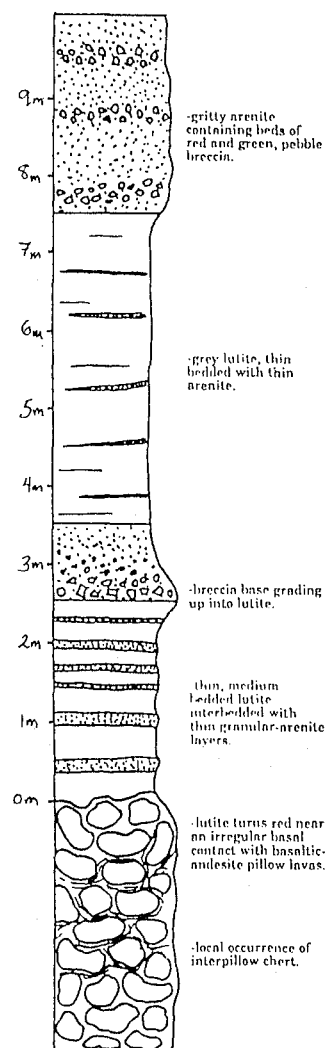
Basalt and basaltic-andesite lava and pillow lavas occurring on Heartbreak Spur are considered to be the extension of the Heartbreak Formation in the central Takitimu Mountains mapped by Houghton, (1977). On the eastern side of Heartbreak Ridge (D44/139757) basaltic-andesite pillow lavas are beautifully exposed in a protruding rock face (Figure 2.1). Siliceous mudstone deposits (Appendix G) surround the chilled margins of pillows at this locality.



Figure 2.1. Photograph of a northeastward facing bluff of basaltic-andesite pillow lavas within the Heartbreak Formation (D44/139757).

Heartbreak Spur is composed almost entirely of basaltic-andesite pillow lavas and lava flows some of which are porphyritic basaltic-andesite. The hill opposite Heartbreak Spur (D44/145750) on the true left of the Wairaki River is also dominated by basaltic-andesite lavas, some of which are pillowed.

While the Heartbreak Formation in the Nugget Hill region is dominated by volcanic rocks, volcanoclastic sediments are locally present. For example a locality on the eastern side of Heartbreak Spur (D44/1395758), is characterised by a contact between basaltic-andesite pillows and volcanoclastic beds which strike approximately NS. There is an irregular contact between basaltic-andesite pillow lavas and bedded lutites interbedded with thin arenite layers. Lutite layers in contact with the pillow lavas show red baked (oxidised) zones. Toward the top of the lutite/arenite sequence a coarse angular rudite layer grades up into grey coloured lutite which is interbedded with even thinner bands of arenite. The grey lutite unit is overlain by repeated layers of a red and green pebbly rudite and gritty arenite beds (Figure 2.2).



On the true right hand side of both the Telford Burn and the Wairaki River where it is joined by the Telford, the rock types are mainly basaltic-andesites with minor interbedded arenite, and a White Hill basaltic intrusive sill, all striking WNW-ESE.

Figure 2.2. Stratigraphic column showing the relationship between basaltic-andesite pillow lavas and volcanoclastic sediments of the Heartbreak Formation (D44/140758).

MacLean Peaks Formation

Volcanogenic rudites, arenites and lutites are the dominant lithologies within the MacLean Peaks Formation. Subordinate volcanic lithologies include basaltic lava flows and pillow lavas similar to those of the Heartbreak Formation (eg; including siliceous mud-grade deposits around chilled pillow margins (D44/144764)). Tuffs are also locally present.

Some lateral variation in lithology within the MacLean Peaks Formation is evident. Voluminous rudites in the central Nugget Hill area are generally well sorted, clast supported and are sub to well-rounded. In the eastern part of the formation, poorly sorted, matrix supported and less well rounded rudites occur as comparatively thin (few metres wide) lenses within thick arenite-lutite sequences. Fewer volcanic lithologies occur in the eastern area.

Phoenix Gully in the south, comprises mainly volcanoclastic rudites, rare arenites and a crosscutting microgabbro dyke. These volcanoclastics strike

approximately EW and form the southern limb of a newly recognised asymmetrical antiform (Map). On the north side of Phoenix Gully there are fewer rudites outcropping than on the south side. Basalts and basaltic-andesites tend to occur on ridge tops which are also trending EW (Map).

Nugget Hill comprises mainly rudites interbedded with arenites and a thin (4-5 m) basaltic-andesite pillow lava. These units have a distinctive NNW-SSE, and can be traced northwards across the Wairaki River.
(153° / 85°W)

To the east of Nugget Hill, arenite interbedded with rudite, lutite and subordinate basaltic-andesite, dominates. A conformable microgabbro of the White Hill Intrusive Suite forms the major ridge crest which runs along the NNW-SSE strike across the Wairaki River.

Distinctive red, hematite staining occurs at three localities, to the northeast, east and south of Nugget Hill (D44/151764, D44/161748, D44/155735) within rudites, and in a coarse porphyritic chrome diopside-rich pyroxene ankaramitic basalt (Figure 2.3) which are all right along strike from one another. The distribution of these three localities is such that they may represent a marker horizon around the locus of the proposed fold in the area. The hematitic staining may be evidence of a minor subaerial influence on this part of the sequence, however it is not definitive. Rocks in the Takitimu Group are generally thought of as being primarily marine although subaerial flows are recognised.

Previously ankaramites have only ever been recorded within the Caravan Formation (Aslund, 1988), the youngest of the Takitimu Group. Recent new observations suggest that they extend further down in the Takitimu Group than previously thought.

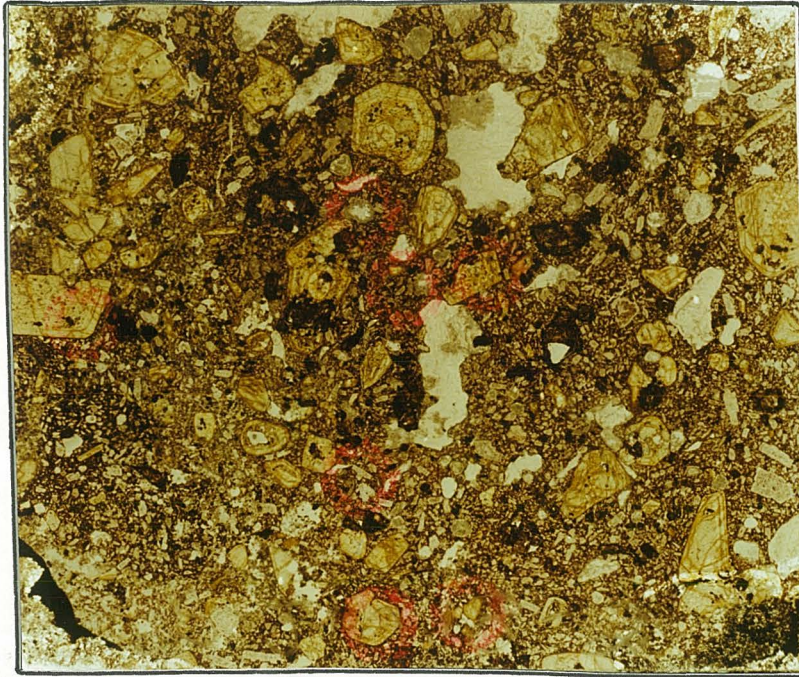


Figure 2.3. Enlarged (x3.5) photograph of a polished section of the ankaramitic basalt (OU 63933). Note the typically large green, concentrically zoned chrome diopside pyroxenes.

VOLCANIC LITHOLOGIES

INTRODUCTION

I have assigned the volcanic rocks of the Takitimu Group ^{into} two different groups: basaltic-andesites, and basalts. These subdivisions are based on mineralogy, modal composition and texture. Although textures were useful in making the subdivisions, similar textures were found to occur in more than one rock type, hence textures alone are not definitive.

The most common minerals in all the volcanic rocks are plagioclase, augite (Appendix A), magnetite and alteration minerals such as chlorite, chlorite-vermiculite, prehnite and various zeolites. A few samples contain small amounts of celadonite, titanite, iddingsite and calcite.

VOLCANIC PETROGRAPHY

Primary Mineralogy

Plagioclase

Plagioclase compositions range from albite to anorthite (An₇-An₉₇). Due to weathering and burial metamorphism, the majority of plagioclases show some sort of alteration, generally sericitisation. Many contain rounded inclusions of pyroxene and crystallographically oriented inclusions of magnetite (Figure 2.4) (Appendix A).

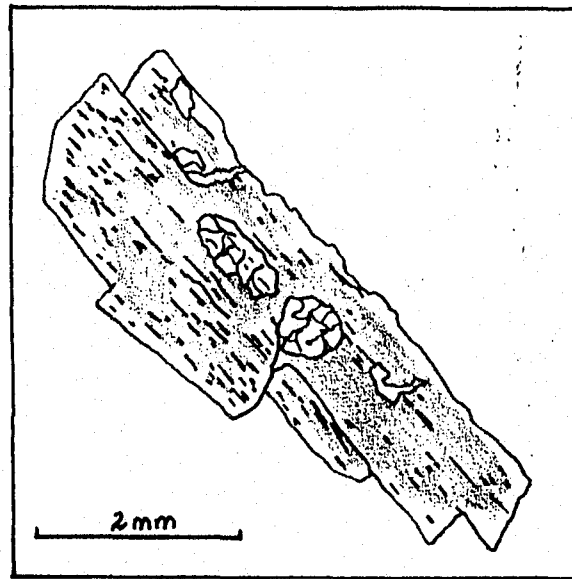


Figure 2.4. Plagioclase phenocryst in a basaltic-andesite (OU 63923) containing large anhedral pyroxene inclusions and crystallographically controlled inclusions of magnetite.

Pyroxene

Augite is the dominant pyroxene in the volcanic rocks of the Takitimu Group in this area, although other compositions such as ferrian augite, aluminian augite, ferrian aluminian-bearing augite, diopside and chromian diopside are also present in some specimens. Pyroxenes are very rarely altered in these rocks, they seem to be the most chemically resistant minerals present. Many contain sub-ophitic overgrowths of magnetite (Figure 2.5) and in some, tiny amounts of analcime have been found.

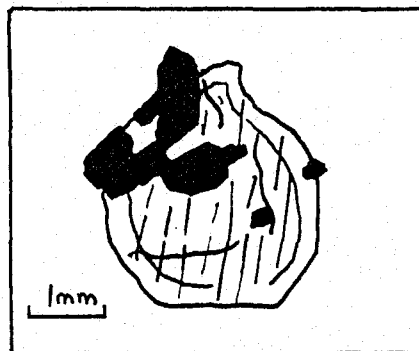


Figure 2.5. Ophitic and sub-ophitic overgrowths of magnetite in a subhedral clinopyroxene phenocryst (OU 63923).

Magnetite

The dominant opaque phase in the volcanic rocks is magnetite, which forms primarily in the groundmass but also as phenocrysts. Its cubic form is usually well developed and is a useful criterion for petrological identification.

Metamorphic Mineralogy

Zeolites

There are seven different zeolite minerals present in the volcanic lithologies of the Takitimu Group. They are stilbite, heulandite, laumontite, thomsonite, mordenite, gonnardite and analcime (Appendix F). The occurrence and distribution of zeolites is discussed in more detail in Chapter 5.

Prehnite

Prehnite is not abundant but it does occur in several samples, usually in the groundmass and in microscopic cross-cutting veins (OU 63972) (Chapter 5).

Alteration Products

Chlorite

Chlorite is the most abundant alteration mineral in all the volcanic lithologies. It occurs as green radiating aggregates which cluster to fill vesicles or replace other minerals such as olivine (Figure 2.6). The characteristic anomalous blue birefringence of chlorite is uncommon in these lithologies. Instead, birefringence of the chloritic phase is more commonly second order colours indicative of mixed layer structures within the mineral lattice (D. S. Coombs pers. comm. 1992).

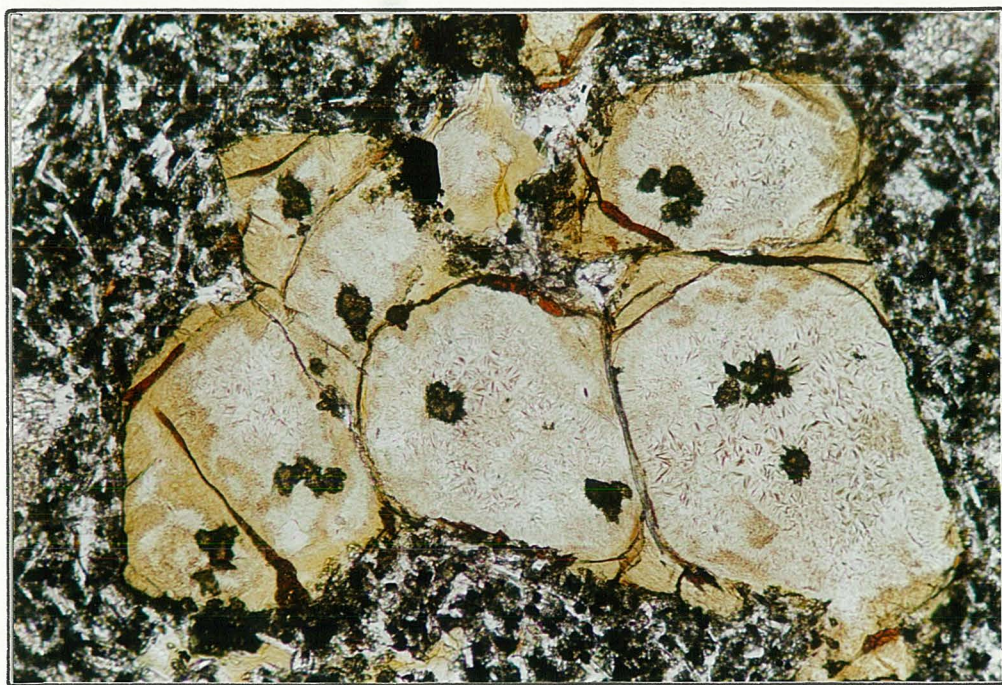


Figure 2.6. Photomicrograph of glomeroporphyritic 'olivines' pseudomorphed by chlorite. Titanite blebs occur in the middle of the grains (OU 63971). Magnification is x40.

Chlorite-vermiculite

Chlorite-vermiculite is a brown micaceous phase which appears from textural relations to be forming at the expense of chlorite (Figure 2.7) (Brown, 1966). In thin section the chlorite-vermiculite looks very much like brown biotite and can easily be misidentified (eg; has similar pleochroism). The most consistent optical difference between the two is that the maximum interference colour of chlorite-vermiculite is about one order lower than that of biotite. A sample containing abundant chlorite-vermiculite was analysed using XRD which confirmed the optical identification (Appendix G). The chlorite-vermiculite most commonly forms around the margin of chlorite grain and appears to grade into the chlorite. All rocks in which chlorite-vermiculite has formed show distinct evidence of weathering (eg; plagioclase alterations). All of the rocks in the Nugget Hill area have undergone some degree of burial metamorphism, but not all contain chlorite which shows alteration to chlorite-vermiculite, this suggests that the alteration from chlorite to chlorite-vermiculite is either related to surficial weathering or localised fluid circulation.

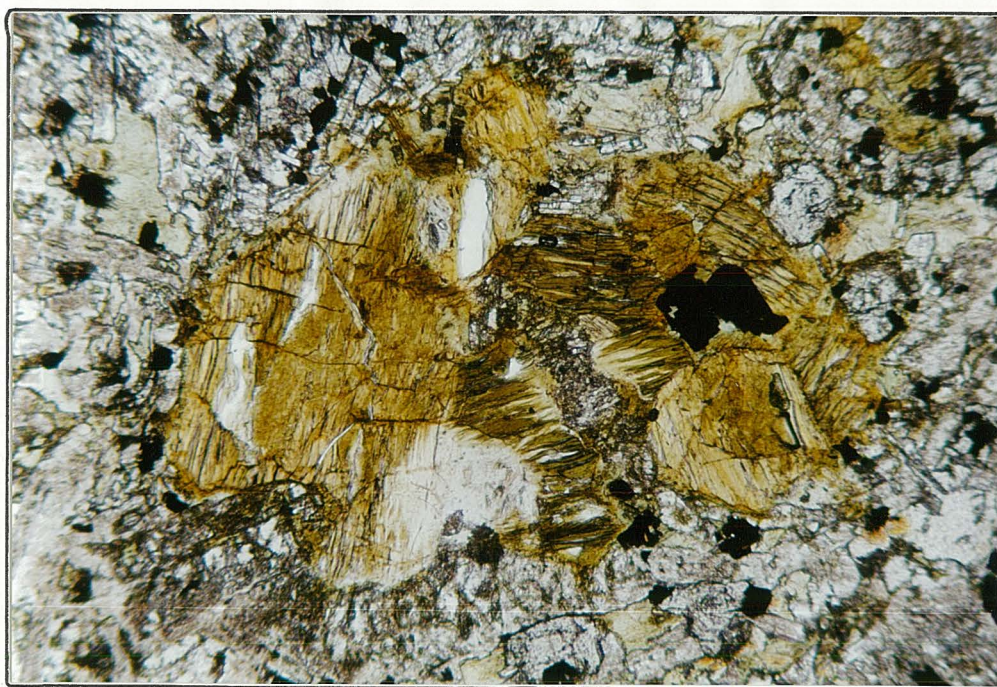


Figure 2.7. Photomicrograph of the chlorite-vermiculite alteration product of chlorite pseudomorphing olivine. Note the similar nature of chlorite-vermiculite to brown biotite (OU 63957). Magnification is x40.

Celadonite

Celadonite is relatively uncommon in Takitimu Group volcanics of this region, although in sample OU 63960 it is quite abundant. Only three samples collected contain celadonite. It generally occurs sporadically in the

groundmass and as an alteration product (Figure 2.8).

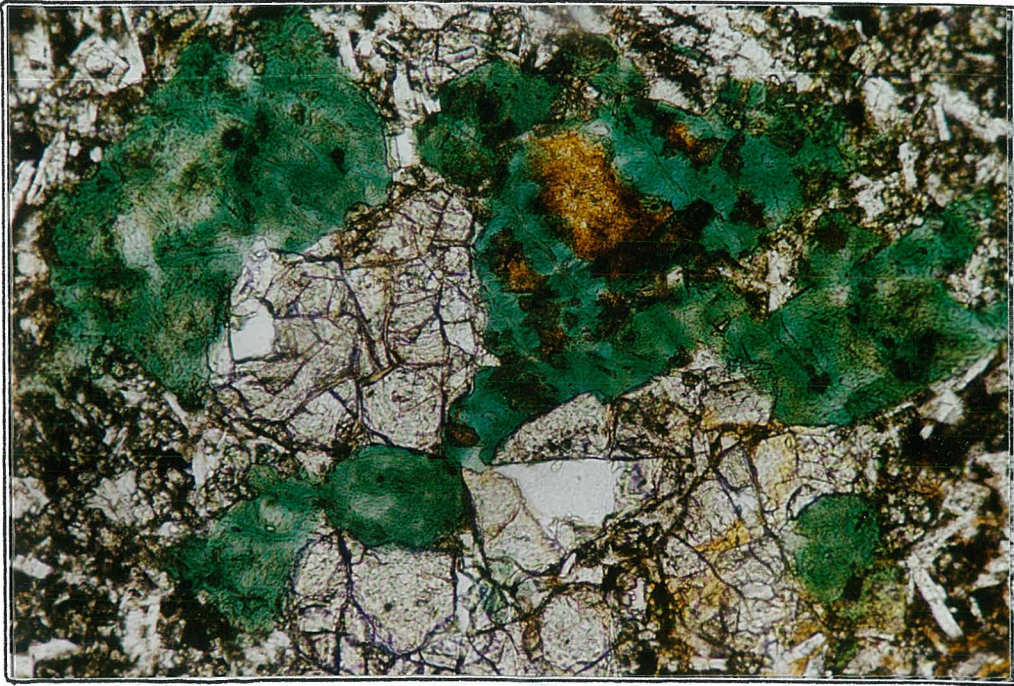


Figure 2.8. Photomicrograph of the conspicuously green alteration mineral, celadonite (OU 63960). Magnification is x40.

Iddingsite

Iddingsite is uncommon and forms as an alteration mineral, usually in the groundmass.

Calcite

Calcite occurs in small quantities dispersed throughout the groundmass of several samples.

Titanite

Titanite is found in the cores of replaced glomeroporphyritic olivine phases (Figure 2.6).

BASALTIC-ANDESITES

Distribution and Field Description

The basaltic-andesites within the Takitimu Group occur in both limbs of the Nugget Hill Anticline. Basaltic-andesites form large piles of pillow lavas and flows. A few flows are thought to be subaerial due to red oxidation colouring and discontinuity. Some pillow lavas have a siliceous sediment (hyaloclastite?) in between pillow rims. North-south trending basaltic-andesite bodies within the MacLean Peaks Formation in the Nugget Hill area are laterally discontinuous, similar in shape to lensoid andesitic flows (MacLean Peaks Formation) mapped in the central Takitimu Mountains (Houghton,

1977). The lensoid shapes of Houghton's andesites were determined on ridge crest outcrops where exposure is more complete. Bodies were mapped along strike until they disappeared on the next ridge (B.F. Houghton pers. comm. 1992). Purely andesitic lavas however, are not present in the Nugget Hill area.

The concentration of basaltic-andesite magmas in a broad zone around the core of the Nugget Hill Anticline, with respect to the rest of the mapped region, indicates that they are a distinct part of the sequence, and can be used to define the extent of the Heartbreak Formation in the Nugget Hill area.

Petrography

These are rocks in which the proportion of groundmass (average grain size 0.05 mm) dominates over the proportion of phenocryst phases (av. grain size. 1.1 mm) and where the silica content is between 52 and 56 wt.% (Fig 2.11a-j). The mineral phases in these basaltic-andesites include plagioclase, augite and magnetite. Zeolites and quartz occur as burial metamorphic phases, and alteration products such as chlorite and chlorite-vermiculite are also present.

Plagioclase is the dominant phase in both the groundmass and as phenocrysts. In the groundmass plagioclases tend to have a skeletal texture (Figure 2.9).



Figure 2.9. Photomicrograph of skeletal plagioclase crystals within an acicular groundmass of plagioclase and magnetite crystals (OU 63959). Magnification is x100.

Plagioclase phenocrysts commonly show normal, and some times oscillatory zoning. They always have some degree of sericitisation and more often than not contain crystallographically oriented inclusions of an opaque mineral and larger pyroxene inclusions (Figure 2.4). Analyses show andesine compositions ranging from An₄₆ to An₅₀ (Appendix C).

Clinopyroxene which also occurs in the groundmass is the next most abundant phenocryst phase. Magnetite is another major interstitial phase in the groundmass, but is generally absent as phenocrysts. Zeolites with or without quartz fill vesicles (Figure 2.10). Quartz can also be seen along with a phyllosilicate, usually chlorite but sometimes chlorite-vermiculite, replacing pyroxene phenocrysts (Figure 2.7).

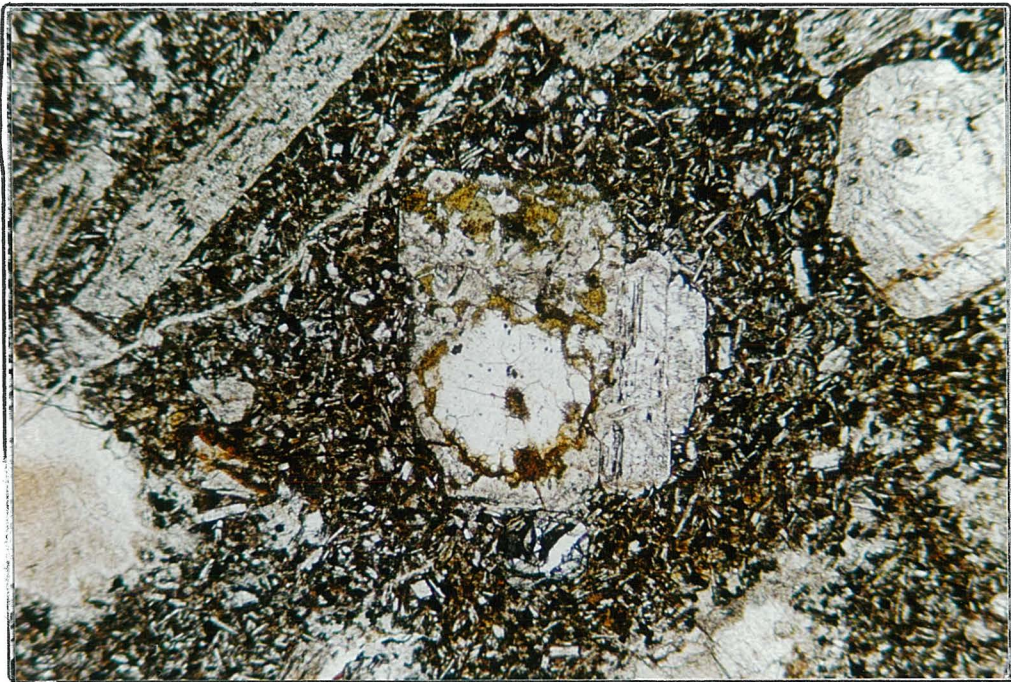


Figure 2.10. Photomicrograph showing the replacement of an augite grain by quartz and chlorite (OU 63932). Magnification is x40.

BASALTS

Distribution and Field Description

Unlike Houghton's descriptions of the Central Takitimu Mountains, where he documented basaltic magmas occurring commonly throughout the Takitimu Group, the basalts in the Nugget Hill region are sparse and are restricted to a small parts of the area mapped here (eg; in the core of the antiform, near the hinge (D44/151748)). In the field the outcrops are generally highly altered and obtaining a fresh sample is quite an ordeal. The basaltic lavas form limited flows and many terminate up section in^{an} accumulation of

pillow lavas.

Petrography

These basalts have a slightly coarser groundmass (0.2 mm) than typical MORBs and comprise predominantly plagioclase, augite and magnetite.

Plagioclase (albite-bytownite) is the dominant phenocryst (av. grain size. 1.1 mm) phase and may be accompanied by augite and magnetite. Plagioclase nearly always shows sericite alteration but commonly has clean rims of dominantly bytownite and sometimes albite.

Magnetite occurs as sub-euhedral crystals which generally have a characteristic cubic form. It is usually medium to fine grained (<1 mm) and occurs throughout the groundmass. Phenocrysts of magnetite sometimes show skeletal textures which are crystallographically controlled. These appear to be preferential resorption features.

A chlorite alteration product replaces subhedral minerals with heavy cracks, similar to the form of olivine. Some of these have small titanite grains in the middle of the crystal.

VOLCANIC GEOCHEMISTRY

Due to hydration during burial metamorphism of the Takitimu Group, all volcanic rock types revealed abnormally high hydrous contents (averaging about 3%). In order to get a better grip on the original compositions of the rocks, the volatile contents were subtracted and the element concentrations were recalculated to the new totals, on an anhydrous basis (Appendix B).

Major Elements

The igneous lithologies of the Takitimu Group in the Nugget Hill area have a very narrow range in SiO₂ from about 52 to 56 wt,%. The various Harker diagrams indicate that they lie within basalt and basaltic-andesite fields, similar to those of Houghton (1985). The major oxide chemistry is very similar to that obtained by Houghton for basalts and basaltic-andesites in the central Takitimu Mountains (Figure 2.11a-2.11j).

TAKITIMU GROUP - VOLCANIC LITHOLOGIES

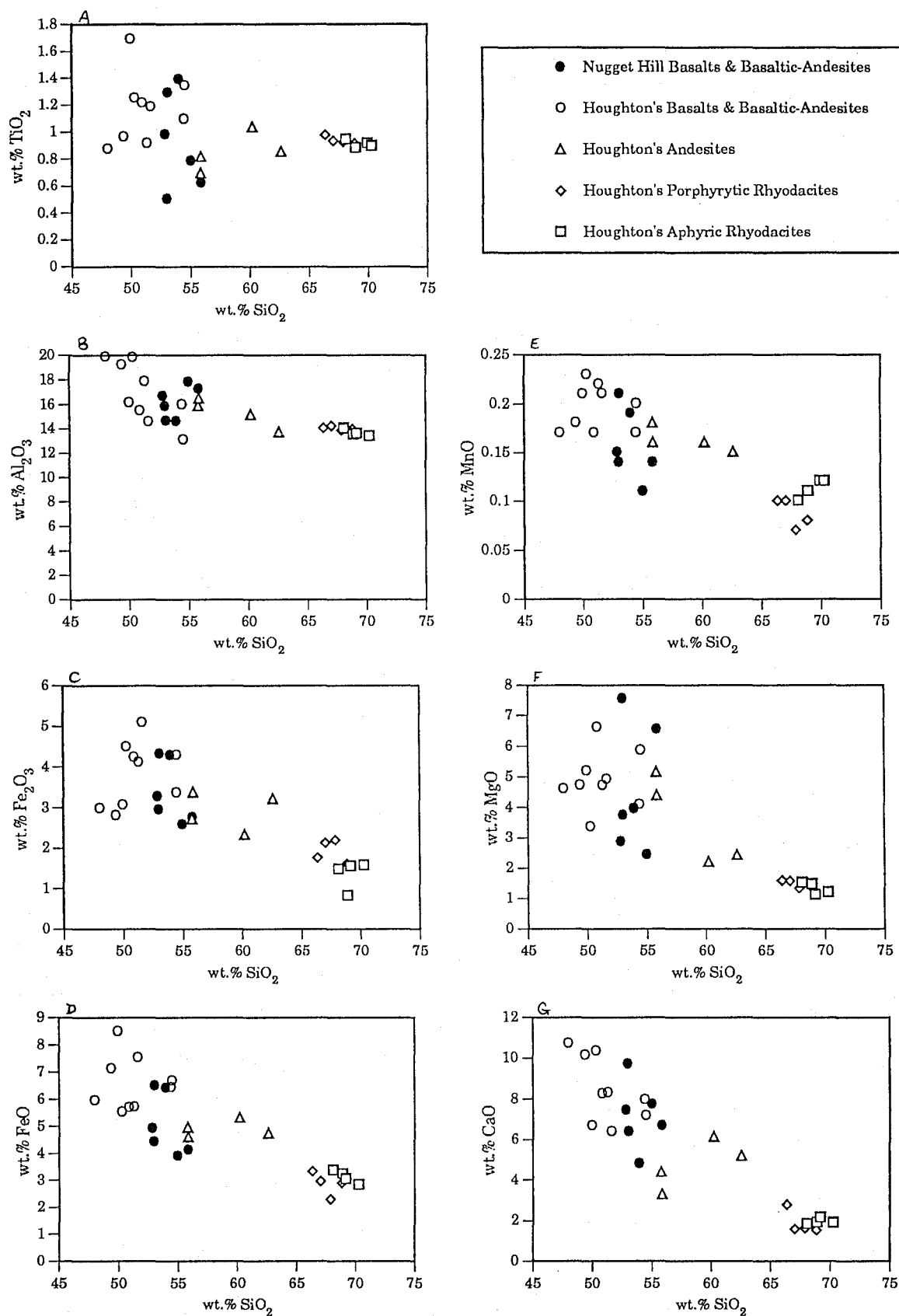


Figure 2.11a-j. Harker variation diagrams for igneous rocks of the Takitimu Group in the Nugget Hill region compared with volcanic rocks of the Takitimu Group in the central Takitimu Mountains (Houghton, (1985).

TAKITIMU GROUP - VOLCANIC LITHOLOGIES

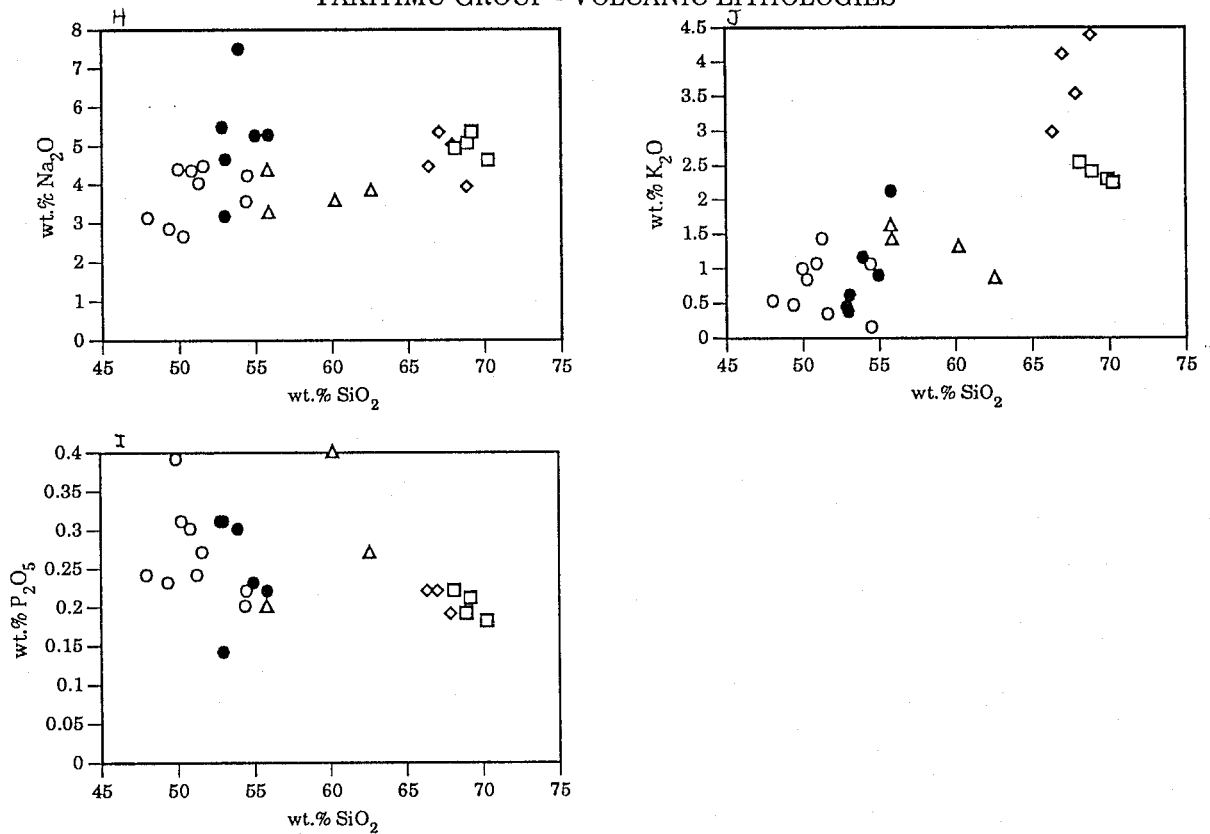


Figure 2.11a-j continued... Harker variation diagrams for igneous rocks of the Takitimu Group in the Nugget Hill region compared with volcanic rocks of the Takitimu Group in the central Takitimu Mountains (Houghton, (1985).

An AFM diagram was plotted (Figure 2.12) to show the compared compositions of the Takitimu Group volcanic lithologies with the volcaniclastics and the White Hill Intrusive Suite. The majority of magmas and volcaniclastics are calc-alkaline in origin rather than tholeiitic.

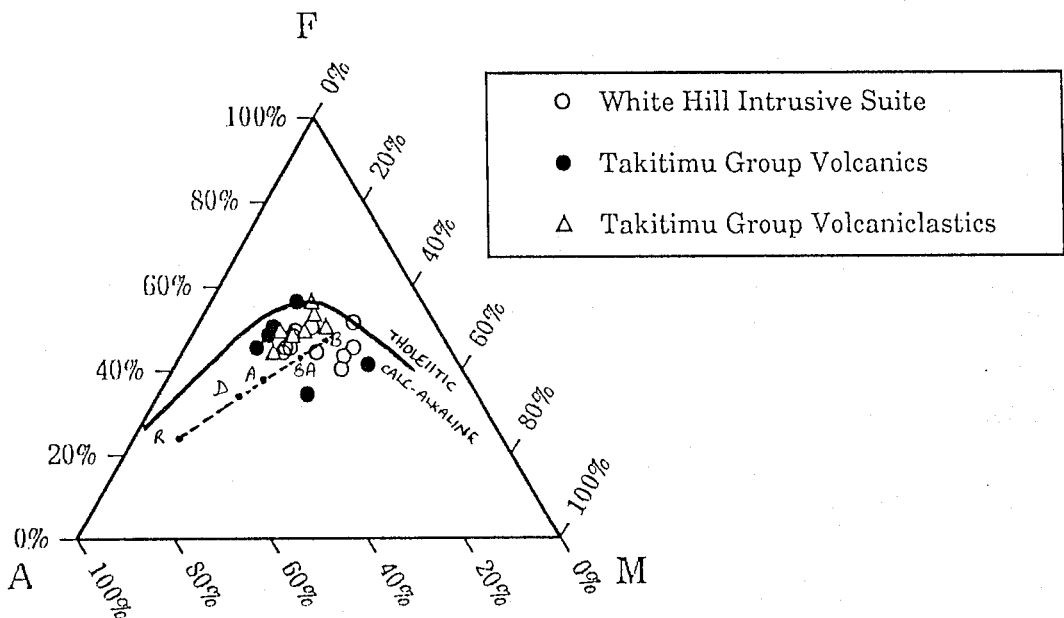


Figure 2.12. An A-F-M diagram showing the calc-alkaline nature of the volcanic lithologies of the Takitimu Group which are similar in comparison with the volcaniclastics and the White Hill Intrusive Suite.

Chemical compositions of plagioclase, the most ubiquitous mineral phase, are summarised in Table 2.13. The majority of plagioclase phenocrysts have anorthite contents ranging from 65 to 80 wt.%. However a single analysis of An₄ was also determined using probe analyses (Table 2.13).

TAKITIMU GROUP IGNEOUS PLAGIOCLASE COMPOSITIONS

	OU 63927	OU 63928	OU 63931	OU 63931	OU 63930
Phenocrysts	Core	Rim	Rim	Core	Rim
SiO ₂	53.64	68.65	55.47	53.20	58.73
Al ₂ O ₃	29.66	19.76	29.80	29.59	26.27
TiO ₂	0.00	0.00	0.03	0.03	0.11
FeO	0.59	0.03	0.69	0.50	0.94
MnO	0.02	0.00	0.00	0.00	0.00
MgO	0.11	0.00	0.05	0.00	0.07
CaO	12.71	0.89	10.93	12.66	9.83
Na ₂ O	3.26	11.54	4.50	4.07	5.35
K ₂ O	0.11	0.11	0.14	0.13	0.28
Cr ₂ O ₃	0.00	0.00	0.00	0.00	0.00
NiO	0.00	0.00	0.00	0.00	0.00
TOTAL	100.10	100.98	101.61	100.18	101.58
Cations on the bases of 32 oxygen atoms					
Si	9.69	11.91	9.84	9.63	10.39
Al	6.31	4.04	6.23	6.31	5.48
Ti	0.00	0.00	0.00	0.00	0.01
Fe	0.09	0.00	0.10	0.08	0.14
Mn	0.00	0.00	0.00	0.00	0.00
Mg	0.03	0.00	0.01	0.00	0.02
Ca	2.46	0.17	2.08	2.46	1.86
Na	1.14	3.88	1.55	1.43	1.83
K	0.03	0.02	0.03	0.03	0.06
Cr	0.00	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00	0.00
Total	19.75	20.03	19.84	19.94	19.81
Ca	67.82	¹⁷ 4.06	56.81	62.74	49.56
Na	31.48	95.34	42.29	36.48	48.78
K	0.70	0.60 44	0.89	0.78	1.66

Table 2.13. Electron microprobe analyses of plagioclases in the volcanic rocks of the Takitimu Group.

High Ca pyroxene is ubiquitous in the phenocryst phase of the igneous rocks (Appendix C). Augite is the dominant analysed pyroxene phenocryst but diopside, endiopside and salite are also present (Figure 2.14). Augite phenocrysts are in general compositionally uniform. Phenocrysts may have slightly higher MgO and FeO contents in the core of the crystal. The analyses show fairly wide ranges in Al₂O₃ (1.5-5.6 wt.%) and TiO₂ (0.2-1.2 wt.%) with the higher wt.% values tending to occur in the cores of phenocrysts. There seems to be a positive correlation between FeO and MnO content of the pyroxenes. Na₂O contents are consistantly low.

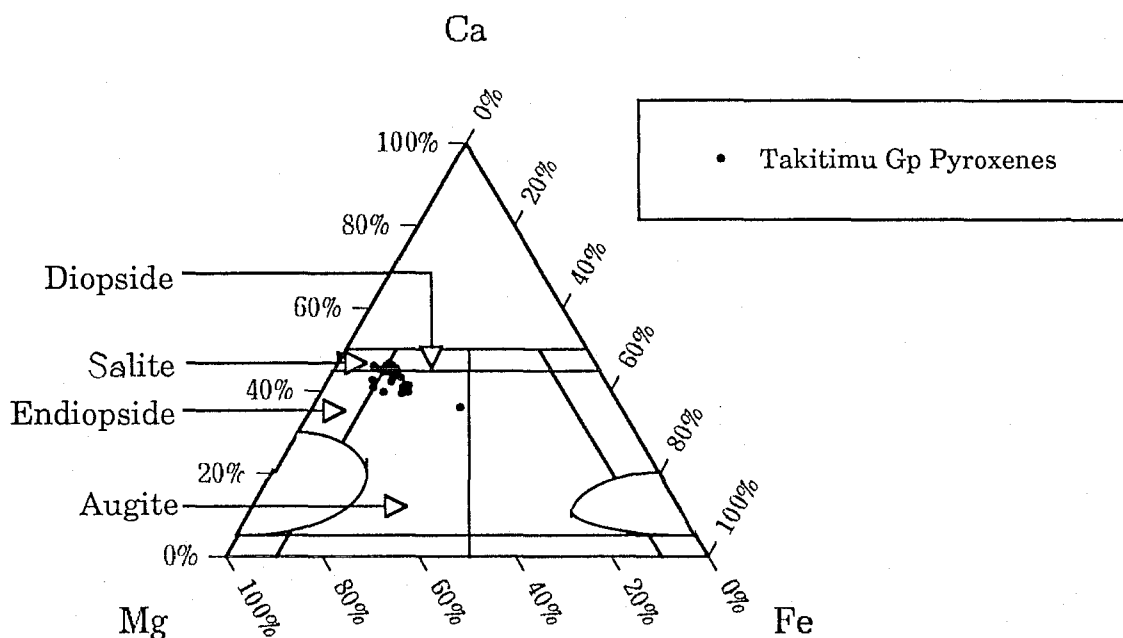


Figure 2.14. Volcanic Takitimu Group pyroxene analyses plotted on the Ca-Mg-Fe diagram.

Normative tables (Appendix D) show albite contents, all have significant quantities of clinopyroxene, and some are orthopyroxene normative. OU 63926 is nepheline normative (6.7%) but petrological observations show no sign of nepheline. Most of the other analysed Takitimu Group volcanic samples are quartz normative and very little quartz was observed. The nepheline normative samples are also olivine normative. Magnetite, ilmenite and apatite are also present in the normative compositions.

Trace Elements
(Table 2.15)

IGNEOUS TAKITIMU GROUP TRACE ELEMENTS

	OU 63926	OU 63931	OU 63932	OU 63927	OU 63928	OU 63953
Pb	5	7	6	4	4	4
Ba	78	180	61	22	53	9
U	3	0	1	1	2	1
Th	2	0	3	1	1	1
Nd	18	21	20	8	21	19
Pr	9	5	6	4	10	7
Ce	19	14	25	4	23	19
La	5	10	11	6	6	7
Sr	229	766	810	447	369	165
Rb	15	33	11	8	16	7
Y	29	20	25	11	33	23
Th	2	0	3	1	1	1
Zr	106	81	128	42	125	93
Zn	107	N.D	60	61	90	73
Cu	165	N.D	108	150	165	159
Ni	16	N.D	15	60	12	11
Cr	9	7	18	155	3	8
V	357	222	199	258	306	232
Ga	20	22	20	18	17	22
Rb/Sr	0.066	0.043	0.014	0.018	0.043	0.042
V/Cr	39.7	31.7	11.1	1.7	102.0	29.0
V/Ni	22.3	N.D	13.3	4.3	25.5	21.1

N.D.=Not Determined

Table 2.15. Trace element abundances (ppm) for the volcanic lithologies of the Takitimu Group.

The Takitimu volcanics show relatively low contents of the large cations (Pb, Ba, Sr and Rb) similar to values obtained by Houghton (1985) for Takitimu lavas of the central Takitimu Mountains. Low large cation abundances are typical of modern island arc lavas (BVSP, 1981 in Houghton, 1985). Nugget Hill lavas have larger ranges in Ba (9-180 ppm) and Sr (165-810 ppm), than basalts and basaltic-andesites Houghton analysed. Anomalously high Sr values occur in two of the more silicic basaltic-andesites from the Nugget Hill area (Figure 2.16). Rb (7-33 ppm) contents also have a larger range and contain several values that are much lower than values of Houghton's (13-25 ppm). These Rb contents are still higher than in typical MORB or island arc suites (BVSP, 1981 in Houghton, 1985). In general the lavas in the Nugget Hill region become more evolved in terms of their large cation content with progressively younger lavas.

TAKITIMU GROUP - VOLCANIC LITHOLOGIES

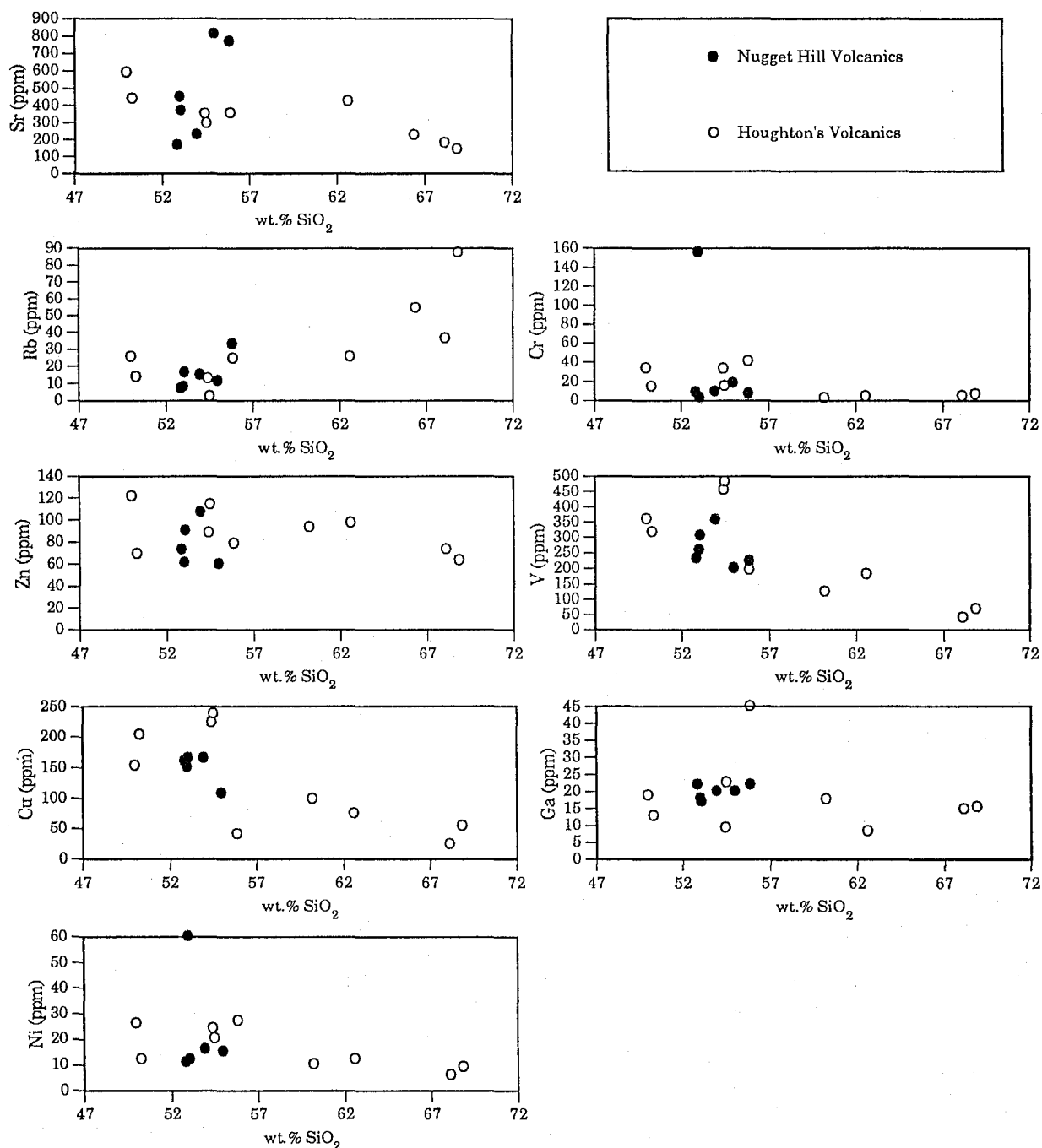


Figure 2.16. Harker variation diagrams for trace elements Sr, Rb, Zn, Cu, Ni, Cr, V, and Ga of the volcanic rocks of the Takitimu Group in the Nugget Hill area. Volcanic lithologies of the Takitimu Group in the central Takitimu Mountains have also been plotted for comparison (Houghton, 1985).

The large, highly charged cation (Th, U, and Zr) contents are similar to those of Houghton (1985) in that they contain very low Th (0-3 ppm) and U (0-3 ppm). Zr (42-128 ppm) contents are not drastically different to Zr (55-120 ppm) contents determined by Houghton (1985) either.

Y (11-33 ppm) contents however, are relatively lower than Houghton's basalt and basaltic-andesite Y contents (25-50 ppm).

Ferromagnesian and chalcophile trace elements such as chromium and nickel are anomalously high in one basaltic-andesite (OU 63927), 155 ppm and 60 ppm respectively, compared with Cr and Ni contents in Houghton's basalts and basaltic-andesites (Figure 2.16). But the overall abundances of Ni and Cr are low, another typical feature of island arc lavas (BVSP, 1981), suggesting that these basaltic rocks were not in equilibrium with mantle olivine. Copper and vanadium contents seem to plot in and around Houghton's data (Figure 2.16). Vanadium values are also typical of island arc series as are the high V/Ni and V/Cr ratios (BVSP, 1981 in Houghton, 1985).

DISCUSSION

Lava flows which predominate among the primary volcanic rocks in the Nugget Hill region reflect their preferential preservation relative to the more easily eroded pyroclastic strata. The Takitimu Group lavas in this area show features typical of moderate to deep water extrusion on gentle slopes. Minor subaerial activity may have occurred in localised regions to give rise to the few discontinuous oxidised flows present. For example the lavas lack features of shallow marine lavas such as abundant pipe vesicles (Moore & Schilling, 1973), scoriaceous pillow fragments and globules and cracking and budding of gas-expanded pillow tubes (Staudigel & Schmincke, 1984). Some basaltic-andesite lavas were intruded under conditions where gas segregation to form pipe vesicles could occur, but all were extruded below the critical level for explosive decompression of magmatic gas (Fisher & Schmincke, 1984).

The vast majority of the world's basaltic-andesites occur in volcanic arc settings above Benioff zones, indicating a genetic link with subduction zone processes. Most basaltic-andesite magmas form by differentiation from basaltic magmas modified by fluids from the subducted slabs and locally by crustal partial melts (Gill, 1981). An origin of this nature is inferred for the volcanics in the Nugget Hill region.

VOLCANICLASTIC LITHOLOGIES

INTRODUCTION

The Takitimu Group in the Nugget Hill area has a very high proportion (at least 60 %) of volcanoclastic facies. The term 'volcanoclastic' has been chosen because it is a defined, non-genetic term for "any fragmental aggregate of volcanic parentage, irrespective of origin" (Cas & Wright, 1987). The difficulties lie in distinguishing between pyroclastic and epiclastic deposits; this term tends to clump them together.

In order to determine the origins of such facies detailed descriptions of each lithology must be made.

LITHOLOGIES

Volcaniclastic rocks in the Nugget Hill area include rudites (defn; consolidated sedimentary rocks composed of rounded or angular fragments coarser than sand.), arenites (defn; consolidated sedimentary rocks composed of sand sized fragments irrespective of composition.), lutites (rocks composed of material that was mud size.) and tuffs. In describing these lithologies, aspects such as physical constituent, composition and texture must be considered.

Physical Constituents: The physical constituents of a volcaniclastic rock refer to the type and nature of the clasts and any other components that are present (Fisher & Schmincke, 1984). The clastic facies in this volcanic succession consist predominantly of fragmental aggregates of basaltic-andesite, arenite and lutite rip-up clasts and crystals. The magmatic clasts vary in vesicularity from dense lava fragments to vesiculated lithics.

Composition: Composition refers to the geochemical, mineralogical and petrological character of a rocks constituents, irrespective of whether it is a lava, pyroclastic or redeposited volcaniclastic (Fisher & Schmincke, 1984). The final composition of the rock may be the end-result of a complex history of processes causing chemical and physical change and do not truly reflect the origins of the magmas. Predictably the compositions of the volcaniclastics in the Nugget Hill area have close affinities with the volcanic and plutonic rocks also present in the region.

Texture: The textural properties of the aggregates reflect on the characteristics inherited from the source, the mode of fragmentation and on characteristics developed during or after transportation and deposition (Fisher & Schmincke, 1984).

Grain Size: The preserved grain size of fragmental aggregates reflects the minimum grain size available at the source point, the type and efficiency of fragmentation, the competency of the transporting and depositing medium to carry that grain size, and the degree of physical abrasion during transportation and deposition. The grains in the Takitimu Group volcaniclastics ranges from blocks 0.5 m in diameter, to silt sized grains.

Sorting: Sorting of the clasts within the aggregates reflects the degree to which the transporting agent has been capable of separating grains of different hydraulic properties and depositing together grains that are hydraulically equivalent. The volcanoclastic aggregates of Nugget Hill are generally poorly sorted according to size, but are reasonably well sorted according to density, especially in the arenites.

Rounding: Partial rounding of fragments appears to be the result of surface processes after the volcanic eruption, in that very few shard shapes were observed. Most of the clasts are angular to subrounded indicating a relatively proximal source. This implies that the primary volcanic rocks had later been eroded and that the clastic components were redeposited (Fisher & Schmincke, 1984).

SEDIMENTOLOGY

Sedimentary structures found in the volcanoclastic sediments of the Takitimu Group can be used to interpret the overall depositional conditions, including modes of deposition and modes of transport. The depositional history of a deposit can be divided into three intervals; pre-deposition, syn-deposition and post-deposition. Sedimentary structures within the rocks are assigned to one of these intervals and are used to construct a ~~probable~~ history and environment of deposition.

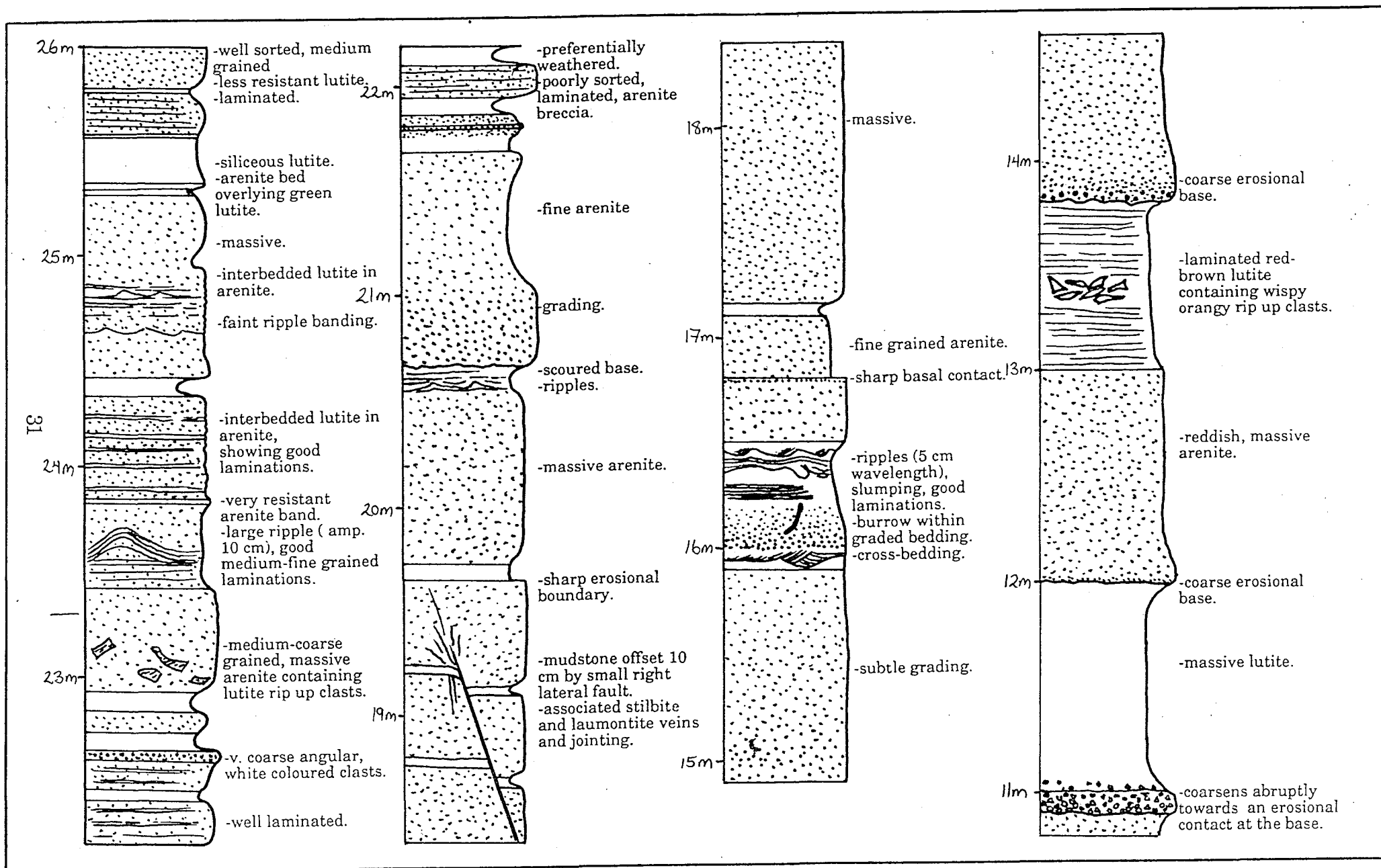
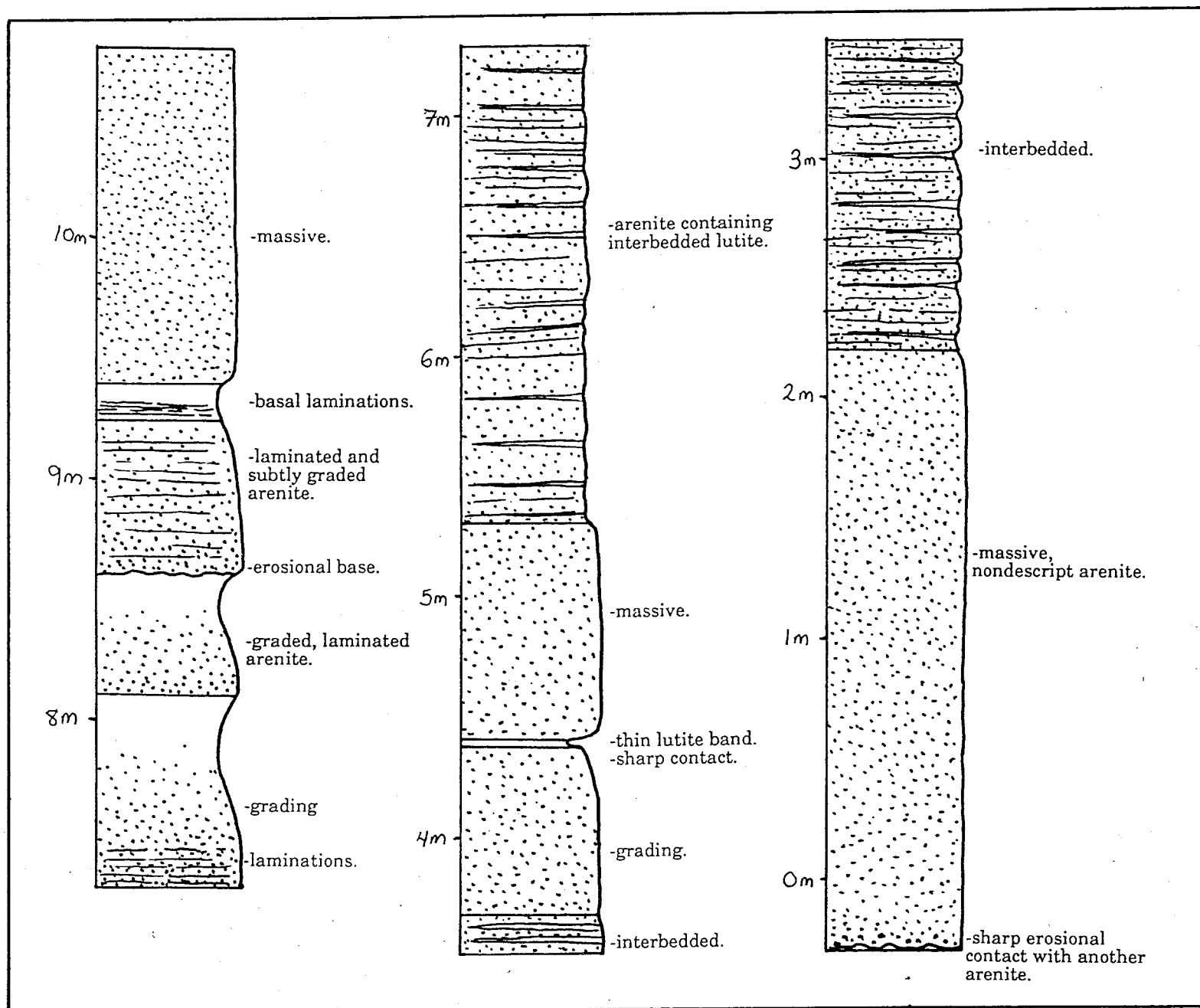


Figure 2.17a. Stratigraphic columns for approximately 26 m of volcanoclastic turbidite sequences down the true right of the Wairaki River section (D44/155776).



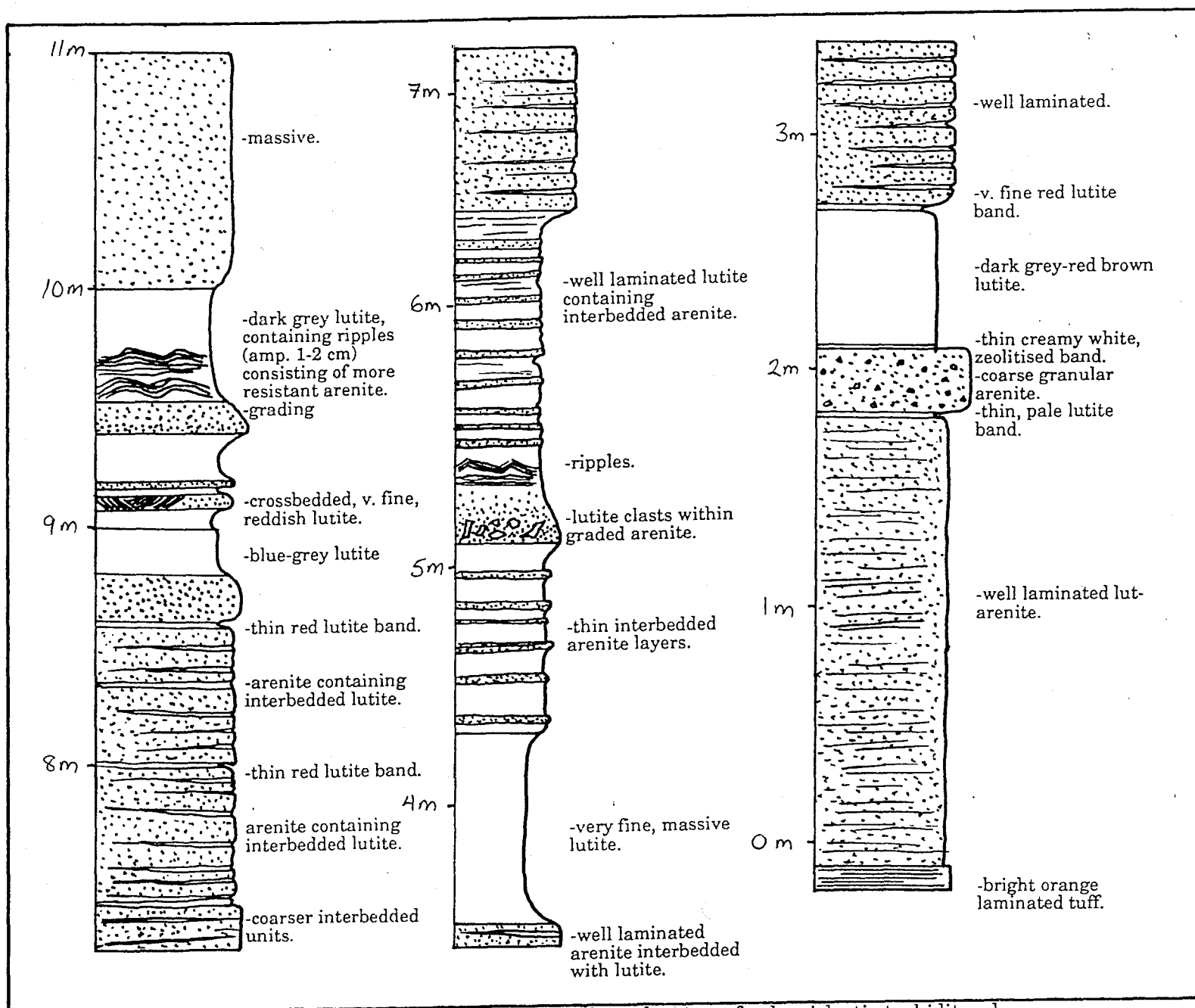


Figure 2.17b. Stratigraphic Columns for approximately 11 m of volcaniclastic turbidites down

Pre-Depositional: Structures produced before deposition are very common in the volcanoclastic rocks of this area. Erosional features in these Takitimu Group volcanoclastics include channels, and scouring. These structures are characterised by sharp irregular transitional boundaries from finer grained lithologies to younger coarser grained lithologies (Figure 2.17b).

Syn-Depositional: In Takitimu Group arenites and lutites, syn-depositional structures are in the form of current structures. Ripples, dunes, cross-stratification laminations, imbrication, and bedding structures are all present in the Wairaki River section (D44/155776), the best exposure of turbidite sequences in the Nugget Hill area (Figure 2.17a). Due to poor outcrop in areas other than in the rivers, very few localities show good depositional structures.

Post-Depositional: Post-depositional features at the Wairaki River section include bioturbation and soft sediment deformation (Figure 2.17a).

Bioturbation is not intense in the turbidite sequence but several burrows have been observed. One (non-branching) burrow in the Wairaki section is 6 cm long by about 0.5 cm wide. It occurs perpendicular to graded sandstone sediments and is infilled by massive sandy-mudstone. At the top of the burrow there is a 1 cm long zone of coarser sediment infilling the burrow. These trace fossil characteristics suggest a combined *Skilothos* and *Nereites* ichnofacies ie; the dwelling structure and depositional conditions suggest *Skilothos* ichnofacies and the host turbidite sequence suggests *Nereites* ichnofacies (Frey & Pemberton, 1984).

Characteristics of Skilothos Ichnofacies observed from trace fossil:

"Vertical, cylindrical boring, densely ramified dwelling burrows. Many intertidal species (eg; crabs) leave the burrows to feed; others are mainly suspension feeders" (Frey & Pemberton, 1984).

"Moderate to relatively high-energy conditions; slightly muddy to clean, well sorted, shifting sediments; subject to abrupt erosion or deposition" (Frey & Pemberton, 1984).

Characteristics of Nereites Ichnofacies observed from trace fossil:

"Bathyal to abyssal, mostly quiet but oxygenated waters, in places interrupted by down-canyon bottom currents or turbidity currents (flysch deposits)" (Frey & Pemberton, 1984).

Frey & Pemberton (1984) also state that "where strong bottom currents issue from submarine canyons or travel along fan channels, components of the *Skilothos* ichnofacies are known to be present"

The characteristically vertical, non-branching, cylindrical form of the burrow observed is indicative of a dwelling structure for intertidal species living in a relatively high energy environment similar to conditions which prevail in a turbidite depositional environment (Frey & Pemberton, 1984).

RUDITES

Rudite Sedimentology

Rudites are the most abundant volcanoclastic lithology in the Nugget Hill area and the most variable in terms of grain size, sorting and rounding. Some rudite outcrops are very similar to volcanic flows and one must look very closely for clast boundaries and juxtaposition of one lithology with another. Identification of a rudite outcrop is hindered in many situations by poor exposures, intense weathering and moss and lichen covering the surfaces. Clearer exposures are found on the tops of ridges, although here only rudite boulders remain (Figure 2.18). The bulk of the rudite mapping was done using such boulders, hence contacts between rudites and other lithologies were not observed away from exposures in the Wairaki River.



Figure 2.18. Photographs of rudite outcrops typical of many in the MacLean Peaks Formation, east of Nugget Hill (D44/16757635). The compass is 10 cm long.

Clast Composition

Clasts consist principally of porphyritic varieties of basalt and basaltic-andesite, large mudstone clasts are present but quite rare. No plant material or fossils were found in any of the rudite units in the Nugget Hill area. Houghton (1977) however, describes rudites in the central Takitimu Mountains as containing plant fragments at the base and *Atomodesma* fossils in the tops of the rudite units.

Rudite Textures

The maximum clast size in rudites of the Takitimu Group in the mapped area, ranges from >2 mm to 0.5 m (Figure 2.19a). Rudites, east and south of Nugget Hill are generally coarser and more poorly sorted than those occurring in the Wairaki River at the foot of Nugget Hill (20-30 cm diameter as opposed to 1-10 cm diameter).

Massive rudites are the predominant lithology in the Nugget Hill area. They are poorly sorted and consist of pebbles, cobbles and boulders of basic volcanic rock types, often set in a tuffaceous sand (Figure 2.19b). Angular rudites show no sedimentary structures, whereas rounded rudite clasts are sometimes imbricated (D44/130745). Crude, large scale grading occurs in the MacLean Peaks Formation and the degree of roundness varies considerably between units and even within units. In general the majority of rudite units are clast supported.



Figure 2.19a. Photograph of the largest (0.5 m) volcaniclastic boulder found in bouldery rudites of the MacLean Peaks Formation (D44/16757635). The compass is 10 cm long.



Figure 2.19b. Photograph of a typical angular to subrounded volcaniclastic pebble rudite from the MacLean Peaks Formation

Discussion

Walker (1975a) proposed a model, for redeposited rudites in turbidite associations, which can be applied to rudites of the Takitimu Group. The massive, clast supported rudites of the Takitimu Group can be correlated with Walker's disorganised-bed conglomerates. This group is characterised by an absence of grading and stratification, and commonly random fabric. Many occurrences of disorganised-bed conglomerates are in submarine-fan environments associated with turbidite sequences (Figure 2.20b). Walker (1975) suggests that in fan systems disorganised-bed conglomerates predominate in canyons and channels above the inner fan (Figure 2.20a). Mass flow movement is a probable mechanism for the deposition of many of the rudite sequences.

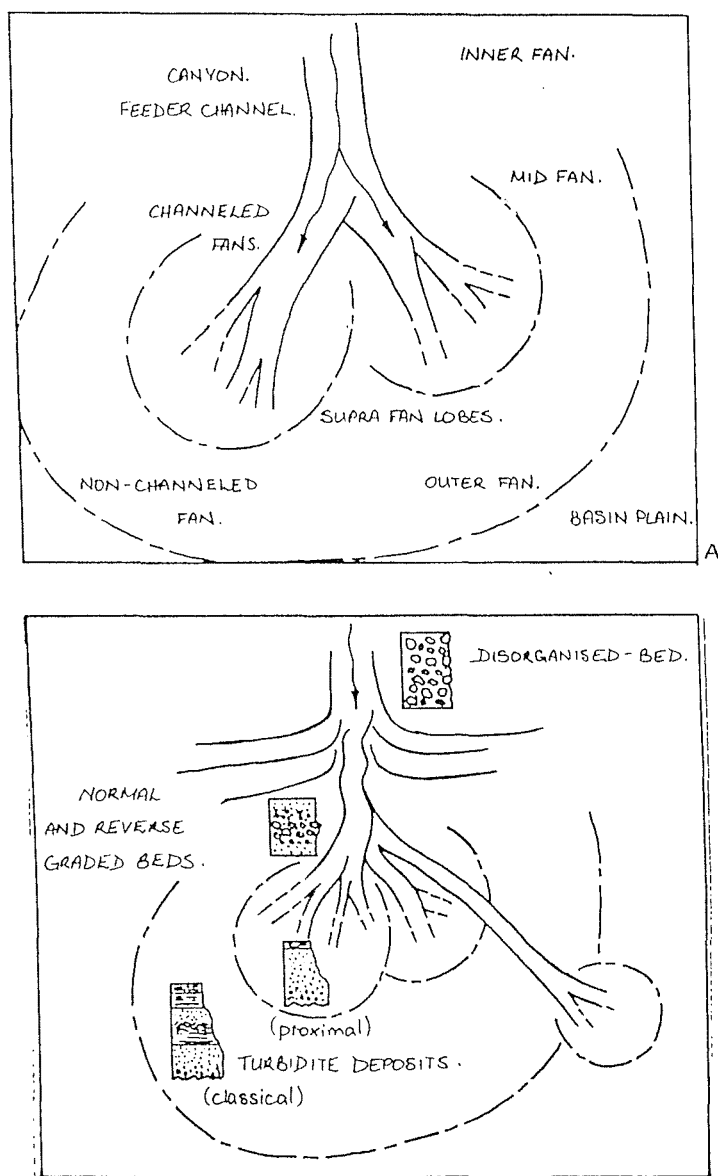


Figure 2.20 a & b. (a) Simplified fan model showing the basics of many ancient and modern fan systems (modified after Walker, 1984). (b) Fan model proposed by Walker (1978). It incorporates an inner fan meandering channel, incised channel (representing a possible down cutting phase), fan extension and lobe development (modified after Walker, 1984). A probable environment of deposition for much of the volcanoclastics in the MacLean Peaks Formation of the Takitimu Group.

ARENITES & LUTITES

Arenite & Lutite Sedimentology

Arenites in this region are always closely associated with lutites, either by forming thin sandstone lenses within them or by containing interbedded lutite layers. Arenites contain the most abundant structures but lutites may also show similar structures. A single locality in the region where sedimentary structures are visible occurs in a section on the true right of the Wairaki River (D44/155776) (Figure 2.21). Here a sequence of ^{subvertical} ~~turbidite~~ ^{beds} ~~deposits~~ striking 170° ~~subvertically~~ are younging towards the east (Figure 2.17a & b).



Figure 2.21a, b & c. a) Photograph and overlay showing near vertical beds of the MacLean Peaks Formation on the true right of the Wairaki River (D44/155776). b) This locality comprises turbidite sequences consisting arenite and lutite beds. c) A large ripple or dune stands-out well in a laminated arenite-lutite sequence. This locality also contains a 10 cm thick, bright orange coloured tuff (see measured section) (Photo taken from D44/1567745).

Structures present include normal grading, scouring, parallel laminations, cross stratification, ripples and dunes. Grain sizes range from medium to coarse sands down to fine muds. Mudstone clasts are abundant within arenites throughout the area, however these deposits consist dominantly of redeposited volcaniclastic material (Figure 2.22). Ripples found in the Wairaki River sequence have an amplitude of 1-2 cm and peaks are about 5 cm apart, parallel laminations and cross laminations are also present at this locality. Paleocurrent directions trending northwards were obtained from the ripples in this sequence (Figure 2.17a). Load casts and “ball and pillow” structures are also present in many of the arenites. Arenite-lutite sequences which contain recognisable structured sequences have been interpreted as ancient turbidite deposits.

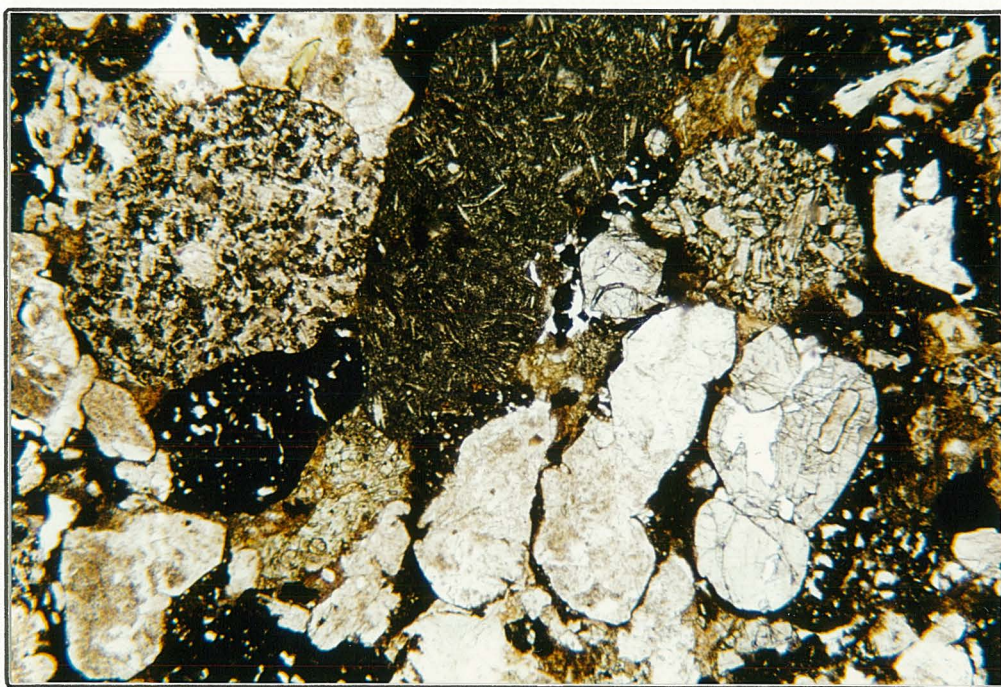


Figure 2.22. Photomicrograph of subrounded volcanic lithic clasts within a volcanogenic arenite from the MacLean Peaks Formation (OU 63939). Magnification is x40.

The Classical Turbidite Model

The sequences in the Wairaki River section comprise numerous classical turbidites. Classical turbidites are those which consist of alternations of sandstones and shales, are parallel bedded without significant scouring or channeling, and where all the beds can be reasonably described using the Bouma sequence (Walker, 1984).

Bouma Sequences

A complete Bouma sequence consists of a massive or graded sandstone deposit (A-rapid deposition), followed by sandy parallel laminations (B-upper flat bed), then a rippled and/or convoluted bed (C-rippled bed), followed by delicate parallel inter-laminations of silt and mud (D), then a mud layer introduced by the turbidity current (E(t)-turbidite mud) and finally a hemipelagic mud layer (E(h)-hemipelagic mud).

The Wairaki River locality (D44/155776) shows several partial Bouma sequences (Figure 2.17a). The most complete Bouma sequence here is about 3 m thick. The top of the previous deposit is insignificantly scoured into by the base of an overlying coarse sand, grading up into massive sandstones. This unit is 2.1 m thick and represents A of the Bouma sequence. It is interpreted to have been deposited in relatively little time (Walker, 1984). B is about 1 m thick and consists of a sandy laminated layer. C contains cross laminations at the base and grades up into well laminated ripples and slump structures within fine mud sediments. The inter-laminations of D are not obvious and the mud layer at the top of the sequence represents both E(t) and E(h) (Figure 2.23).

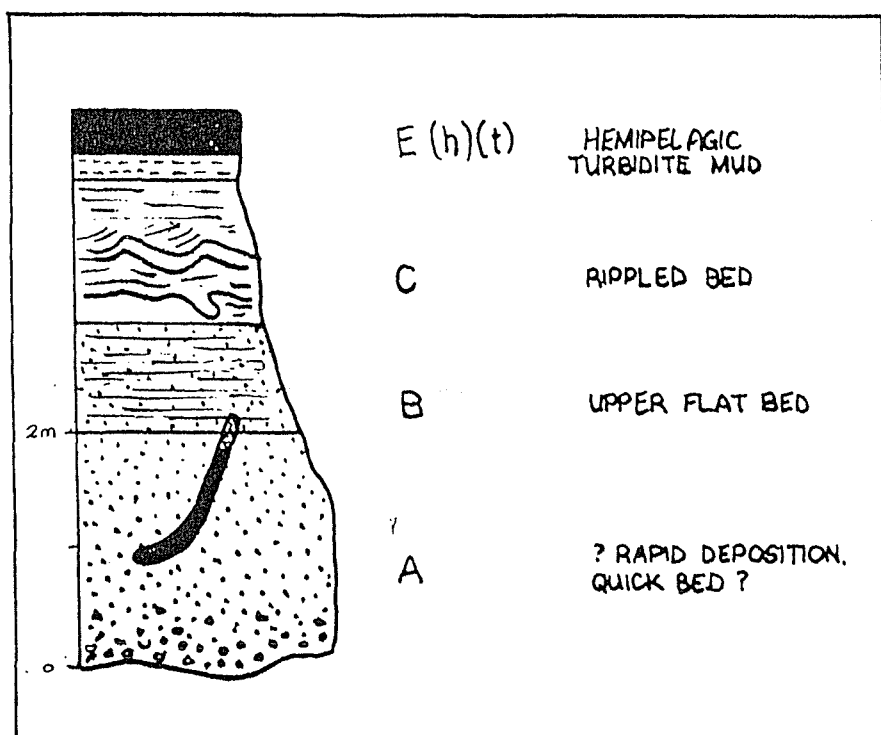


Figure 2.23. Four divisions of the Bouma sequence found in turbidites of the MacLean Peaks Formation in the Wairaki River section (D44/155776). A) Scoured base, grading from coarse sand to fine sand. B) Sandy parallel laminations. C) Ripples and small scale slumping. E(h)(t) turbidite mud and hemipelagic background mud of the basin.

Discussion

The normally graded arenites and lutites are interpreted as turbidity current deposits. The thicker beds within the turbidite sequence are thought to be more proximal than thinner beds which are considered to be distal. Sequences of thinly and thickly bedded turbidites have been described from continental margin environments, modern arcs and in ancient volcaniclastic terrains. Walker's (1984) fan model suggests that the arenites and lutites are deposited on the outer fan and basin plain (Figure 2.20b).

Arenite Petrography and Modal Composition

In order to compare and describe the nature of the source of the Takitimu arenites, eleven Takitimu Group sandstones were point counted. More than 400 points were counted in each sample. Less than a 5% error in the reliability of these point counting results was obtained (Van der Plas & Tobi, 1965). The categories counted were quartz (monocrystalline & polycrystalline), feldspar (plagioclase), lithics (intermediate-mafic volcanics, silicic volcanics, plutonic and sedimentary), heavy minerals (magnetite, pyroxene, and hornblende), secondary and alteration minerals (zeolites, chlorite (matrix & alteration), smectite, matrix, calcite, limonite, celadonite and iddingsite). Other minor categories which were counted include glass and voids (Figure 2.24).

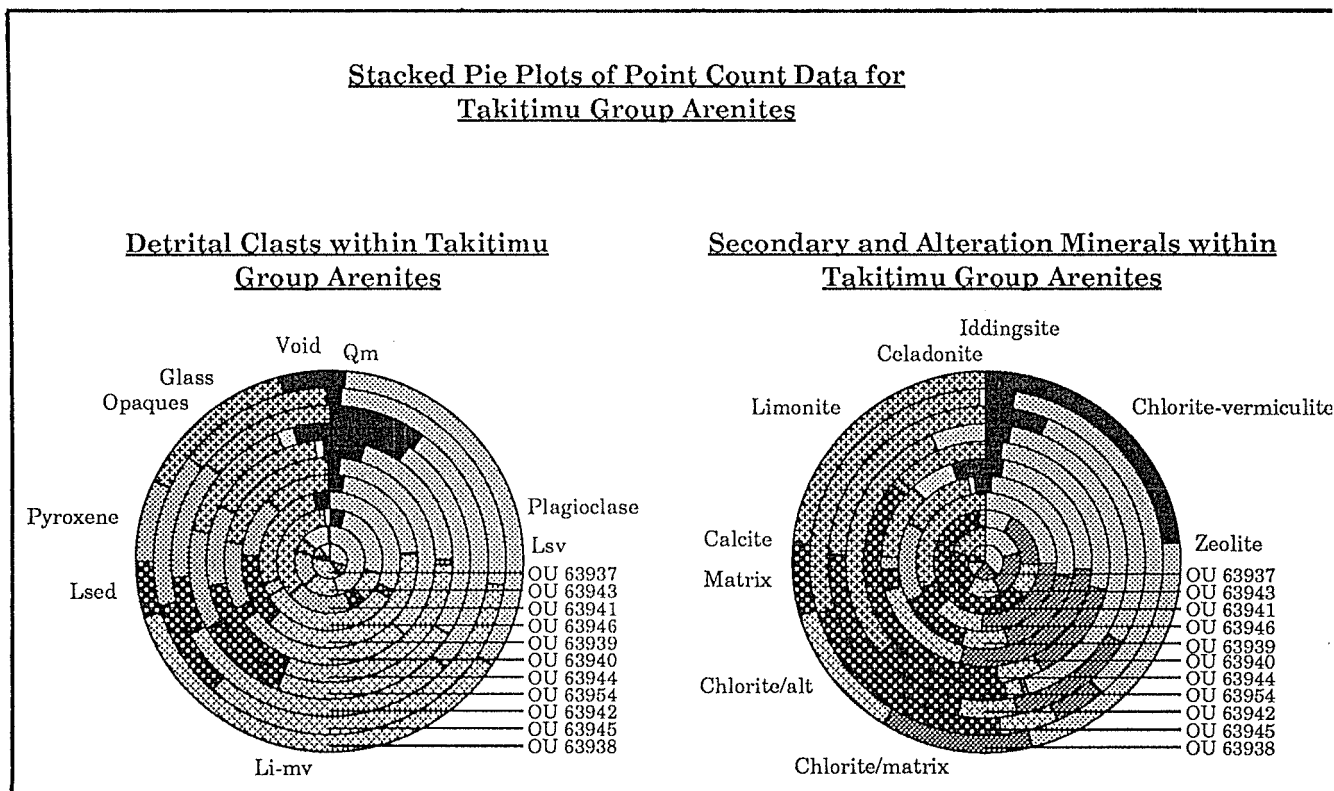


Figure 2.24. Stacked pie plots for eleven point counted arenite samples from the MacLeans Formation in the Takitimu Group (Appendix E).

The mineralogy of arenites in the Takitimu Group consistently indicates a volcanic origin for the sediments (Appendix E). The dominant rock forming clasts are the volcanic lithics, in particular the intermediate to mafic volcanic lithics, along with plagioclase feldspar, pyroxene and magnetite. The most abundant secondary and weathering minerals are zeolites and chlorite. Limonite, calcite, celadonite, iddingsite and smectite are also present but only in small amounts. These minerals fill pore spaces and occur as alteration products of other grains. Clast shapes are generally angular to subrounded, and average grain-sizes vary from 0.1 mm to 3 mm.

A QFL diagram based on this data is shown in figure 2.25. Notice, there is relatively little quartz in the sandstones of the Takitimu Group in this area. Any quartz that was present is dominantly monocrystalline, with minor polycrystalline quartz. This reflects the calc-alkaline nature of the volcanic rocks from which these sediments were derived. Plagioclase feldspar and volcanic lithic clasts are present in an approximately 50:50 ratio. The volcanic lithic to total lithic ratios indicate that 70-90 % of all the lithic clasts are volcanic lithics (Appendix E).

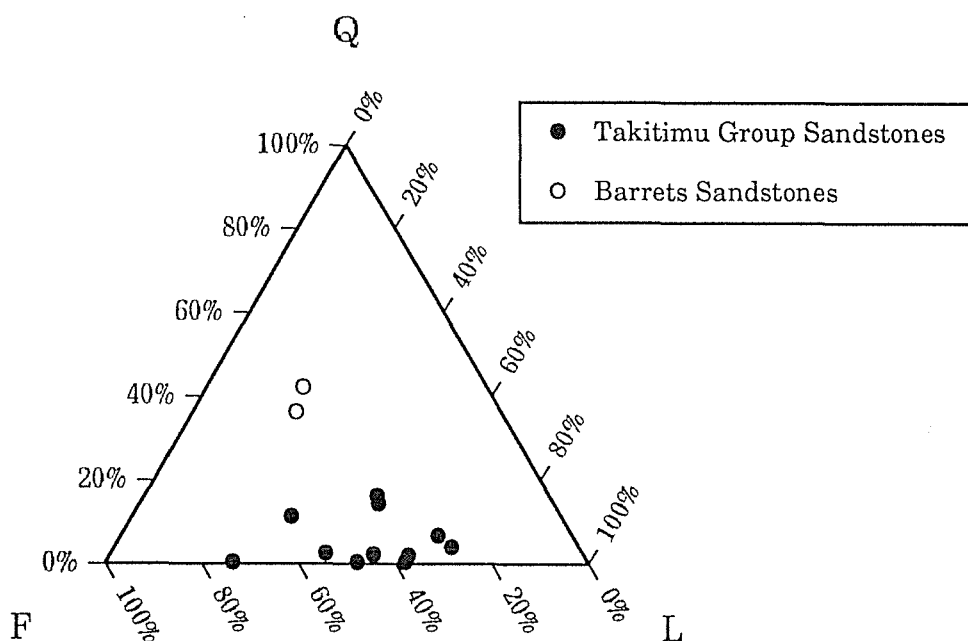


Figure 2.25. Distribution of Takitimu Group arenites and sandstones from the Barretts Formation on a Q-F-L diagram.

Arenite & Lutite Geochemistry

Major Elements

The Takitimu Group arenites and lutites in the Nugget Hill area have very similar major element geochemistry to the lithologies of the Takitimu Group volcanics and the White Hill Intrusive Suite (Figure 2.26a-j). The SiO₂ contents of the samples analysed range from 49.5 to 51.4 wt.%. The compositional gap between 49.5 and 51.4 wt.% SiO₂ is similar to the gap in the White Hill Intrusive analyses between 49.2 and 51.8 wt.%. The correlation of the geochemical gap in the arenites with a gap in the White Hill Intrusives indicates that this gap could be real and not just due to sampling biases. Sample OU 63940 has an anomalously high TiO₂ (1.63 wt.%) content with respect to the other Nugget Hill analyses (Appendix B). These observations indicate derivation of the arenites and lutites, from volcanic lithologies similar to the primary volcanics of the Heartbreak Formation.

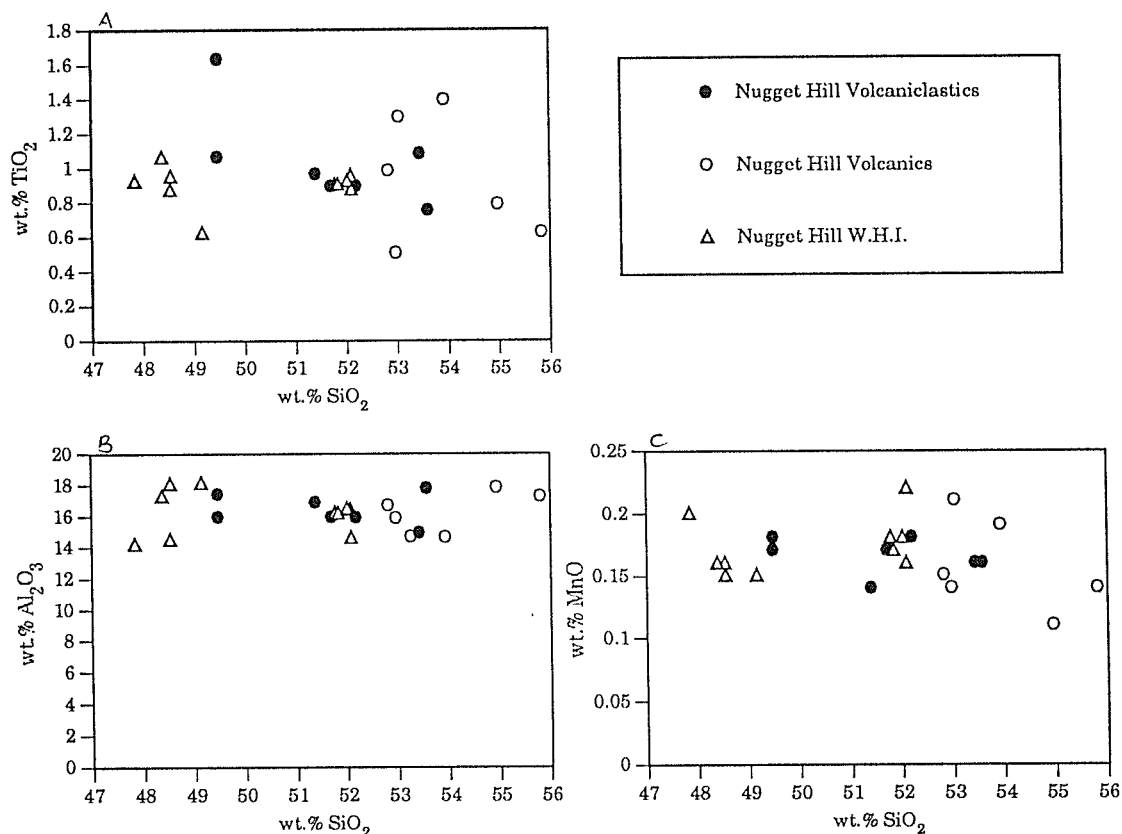


Figure 2.26a-j. Harker variation diagrams for volcaniclastic rocks of the Takitimu Group compared with igneous rocks of the Takitimu Group and the White Hill Intrusive Suite.

TAKITIMU GROUP - VOLCANICLASTIC LITHOLOGIES

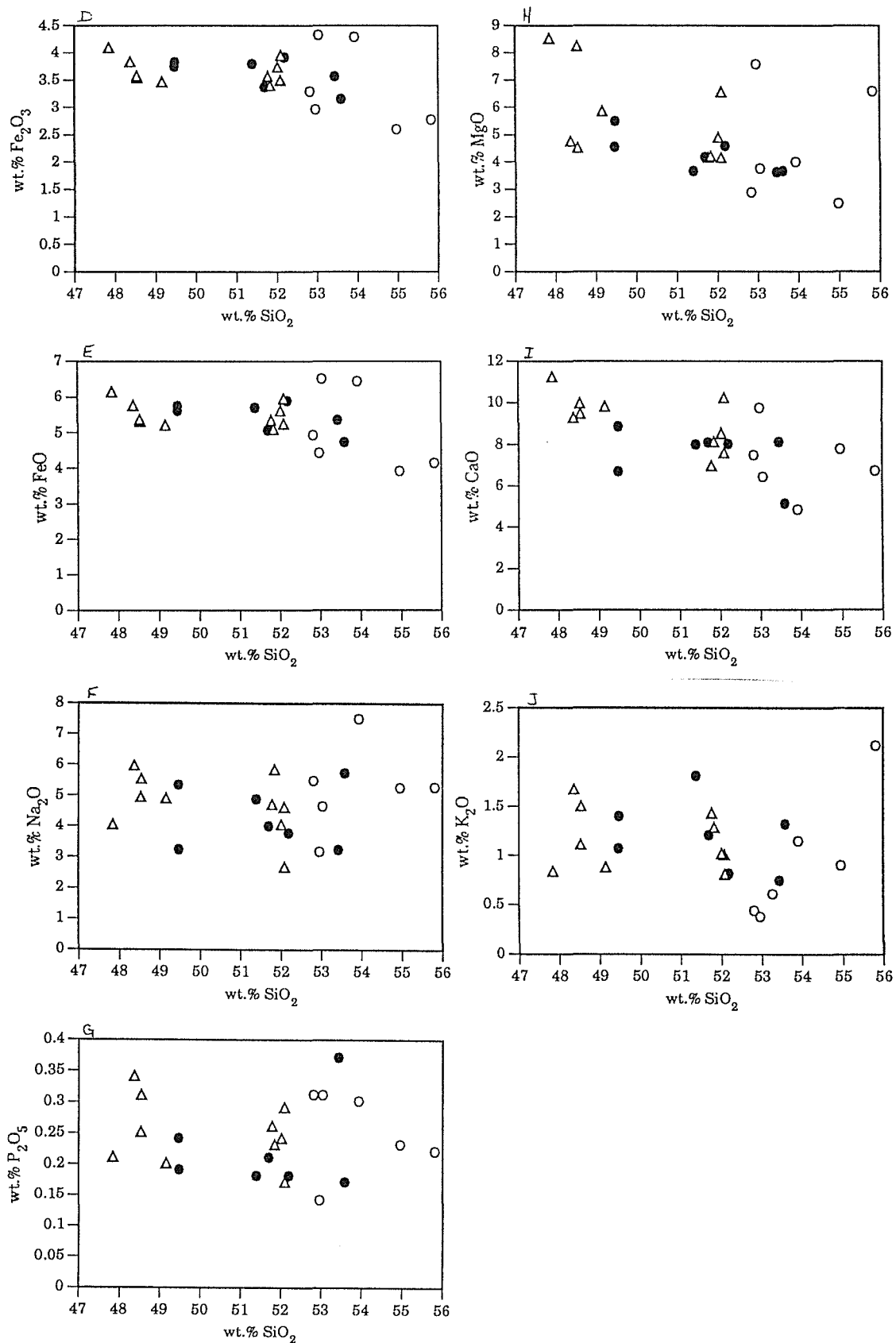


Figure 2.26a-j continued... Harker variation diagrams for volcaniclastic rocks of the Takitimu Group compared with igneous rocks of the Takitimu Group and the White Hill Intrusive Suite.

A plot of $\text{TiO}_2\text{-MnO*10-P}_2\text{O}_5\text{*10}$ also indicates the very similar nature of the volcanoclastic rocks to the volcanic rock of the Takitimu Group and the White Hill Intrusive Suite (Figure 2.27). The figure shows that the volcanoclastic sediments were eroded from rocks showing magma compositions from island arc tholeiites to calc-alkaline basalts.

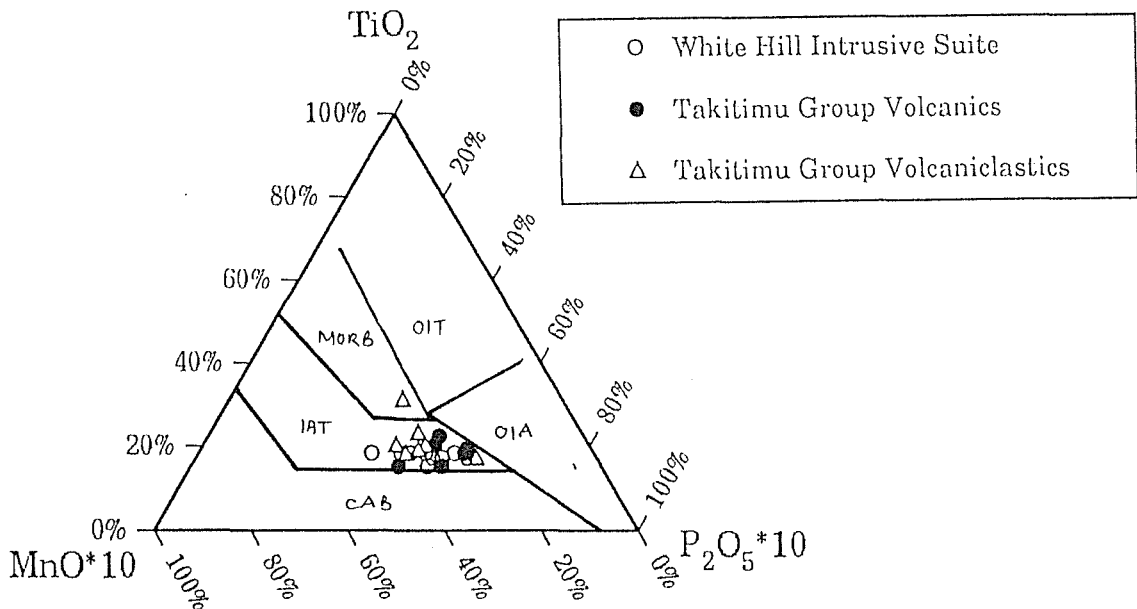


Figure 2.27. The distribution of analysed volcanoclastic rocks of the Takitimu Group compared with igneous rocks of the Takitimu Group and the White Hill Intrusive Suite on a $\text{TiO}_2\text{-MnO-P}_2\text{O}_5$ tectonomagmatic discrimination diagram for oceanic basaltic rocks (after Wilson, 1989).

Normative calculations on arenites and lutites are almost identical to results from volcanic calculations. Most are quartz normative with only two analysed volcanoclastic samples being nepheline normative. OU 63937 and OU 63940 are neither quartz or nepheline normative and are calculated to contain clinopyroxene, orthopyroxene and olivine. The rest are all clinopyroxene normative but may contain orthopyroxene or olivine depending on whether they are quartz or nepheline normative respectively.

Trace Elements
(Table 2.28)

VOLCANICLASTIC TAKITIMU GROUP TRACE ELEMENTS

	OU 63947	OU 63954	OU 63937	OU 63955	OU 63944	OU 63956	OU 63940	OU 63948
Pb	6	9	4	4	7	11	2	5
Ba	81	76	121	91	87	80	100	0
U	0	0	1	0	0	0	3	2
Th	0	0	0	0	0	0	2	1
Nd	15	27	12	10	14	17	15	9
Pr	8	8	8	9	6	4	4	2
Ce	9	35	15	9	21	10	12	7
La	4	11	5	0	5	7	5	3
Sr	1372	3162	848	1050	1784	154	587	38
Rb	12	10	23	49	15	18	41	5
Y	23	32	24	22	26	21	19	11
Th	0	0	0	0	0	0	2	1
Zr	85	130	82	64	96	94	69	50
Zn	96	82	64	63	84	112	68	55
Cu	121	173	53	85	92	61	64	70
Ni	24	18	18	16	18	26	26	13
Cr	41	24	24	21	25	63	35	14
V	282	239	181	257	276	227	346	139
Ga	18	18	18	21	17	18	22	26
Rb/Sr	0.009	0.003	0.027	0.047	0.008	0.117	0.070	0.132
V/Cr	6.9	10.0	7.5	12.2	11.0	3.6	9.9	9.9
V/Ni	11.8	13.3	10.1	16.1	15.3	8.7	13.3	10.7

Table 2.28. Trace element abundances (ppm) for volcaniclastic arenites and lutites of the Takitimu Group.

As for the major elements contents, the trace element contents of arenites and lutites are very similar to those of the Takitimu Group volcanics and the White Hill Intrusive Suite. Rubidium and strontium abundances are the exception. Rb (5-49 ppm) and Sr (38-3162 ppm) contents span a much larger range and are considerably higher in some of the arenite samples than in the primary volcanic rocks or the intrusive rocks (Figure 2.29). Sr and Rb tend to substitute readily into feldspars (Wilson, 1989). Volcaniclastic arenites especially tend to concentrate the feldspars and would hence increase in Sr and Rb contents accordingly.

TAKITIMU GROUP - VOLCANICLASTIC LITHOLOGIES

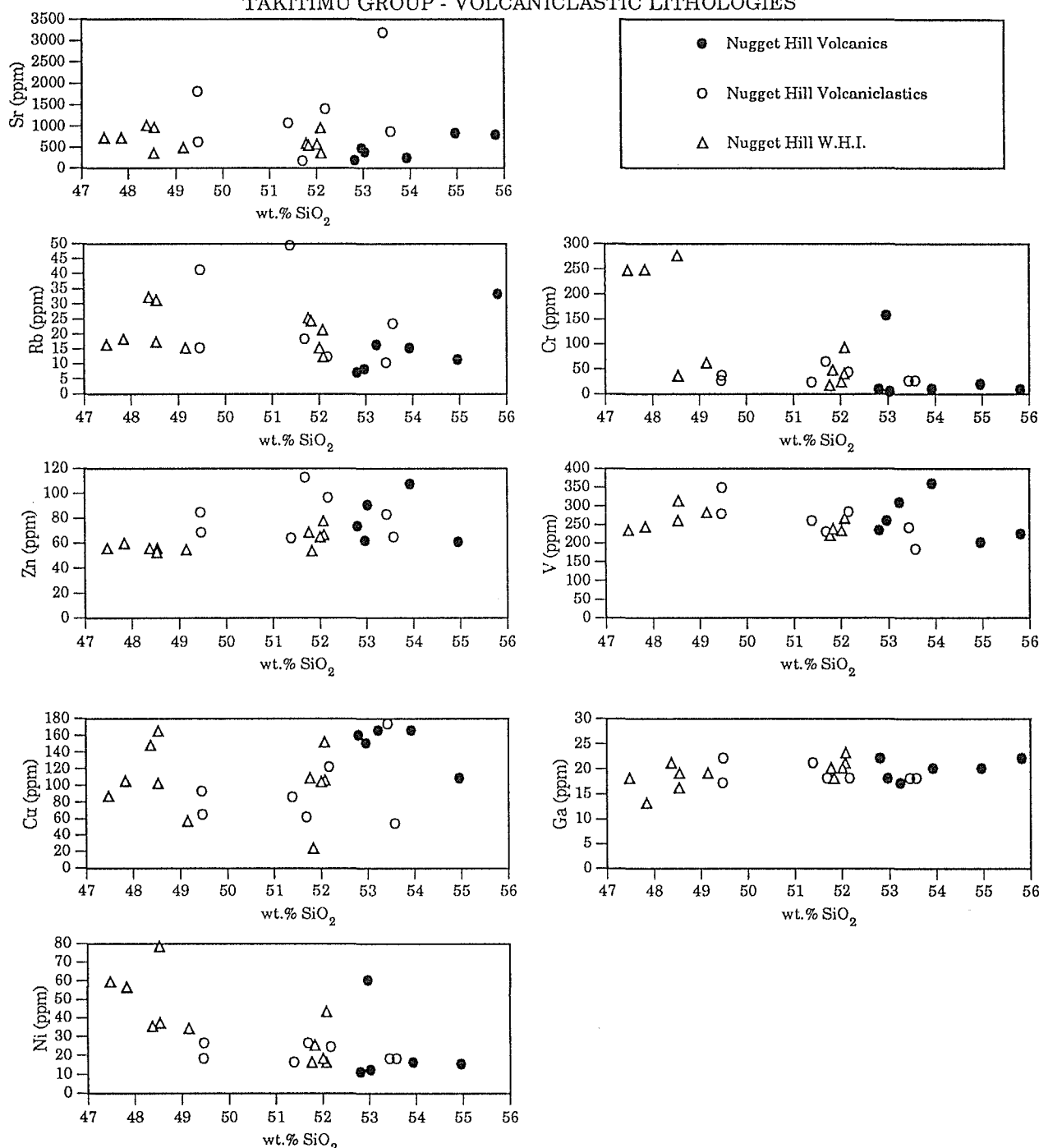


Figure 2.29a-h. Harker variation diagrams for trace elements Sr, Rb, Zn, Cu, Ni, Cr, V and Ga for volcaniclastic rocks of the Takitimu Group compared with igneous rocks of the Takitimu Group and the White Hill Intrusive Suite.

TUFF

Field Description

Very few tuffs were recognised in the Nugget Hill area; there are only two mapped localities (D44/155776 & D44/157762) and these are both thought to be the same bed (Map). This tuff is about 10 cm thick and has a distinct orange colour. It is very fine grained and fractures conchoidally. Faint bedding laminations of alternating dark and light layers which are present may be a result of several eruptive pulses one after another. No other internal structures

are visible.

In the western part of the Wairaki River section this tuff can be seen striking across the river and is disrupted by several discontinuities. It is offset four times within the width of the river (about 7-8 m), by small faults. On the northern side of the river there is a pair of faults one with a left lateral offset and the other with a right lateral offset. In the southern half of the river section two more faults stack the tuff bed in a right lateral thrust sense. There are several zeolite veins associated with the micro-faults (Figure 2.30).

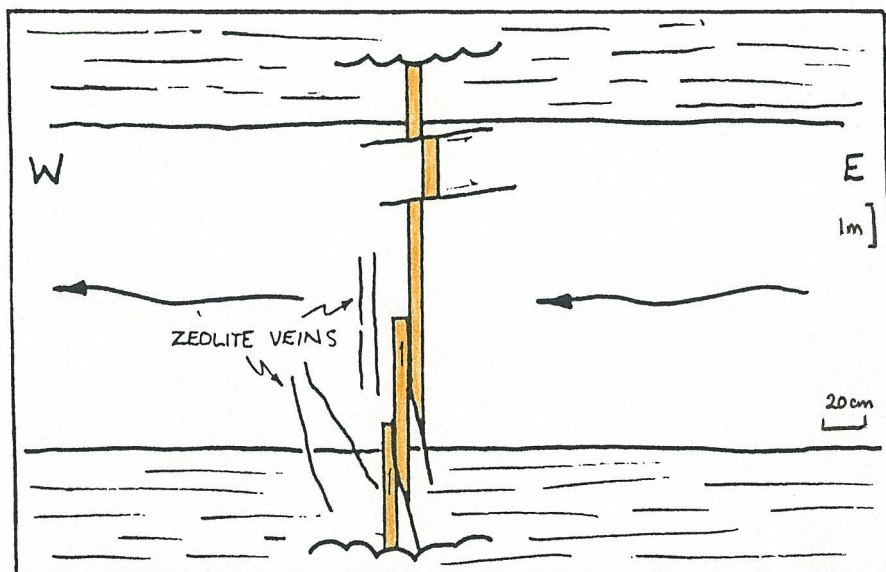


Figure 2.30. Bright orange tuff which strikes across the Wairaki River (D44/155776) is offset by about 10 cm by left lateral, right lateral and reverse faults.

DEPOSITIONAL ENVIRONMENT & PROVENANCE OF VOLCANICLASTICS

Evidence for derivation from a volcanic arc setting has been established using geological, geochemical and analytical techniques. The close field associations between the Takitimu Group volcanoclastics, volcanics and the White Hill Intrusives, their similar geochemistry, lithological and mineral compositions all indicate that they formed in a closed system. Magmatism gave rise to primary volcanic lithologies of the Takitimu Group and eventually to the White Hill Intrusive Suite (Chapter 3). Continuous erosion and the development of drainage networks within the system gave rise to the accumulation of volcanoclastic materials derived directly and indirectly from the original arc system.

The distribution, physical characteristics and discontinuous nature of volcanoclastic sediments in the Nugget Hill area suggest that they were

deposited as part of a large fan system coming directly off the volcanoes into a marginal to deep marine basin flanking the arc system.

Fan Model

Walker's (1978) proposed simplified fan model (Figure 2.20a) can be used to explain the various facies observed in the Nugget Hill area. This model involves a feeder channel (inner fan), which branches out into a smaller channeled (mid fan) fans which form suprafan lobes. Non-channeled fans form in the outer fan and pass in to the basin plain further out.

The feeder channel slopes down into the basin and contains disorganised-bed conglomerate deposits, debris flows and slumping. Inversely to normally graded conglomerates develop in the channelised fan. Out towards the suprafan lobes and into the non-channeled fan, proximal and classical turbidites are deposited (Figure 2.20b).

Particulate movement of granular sediment produces tractional structures such as cross-stratification, dunes and ripples. Mass-movement processes frequently deposit a massive, structureless aggregate, although low sediment concentration, low viscosity mass flows or the trailing tails of mass flows may also produce some of the tractional sedimentary structures observed.

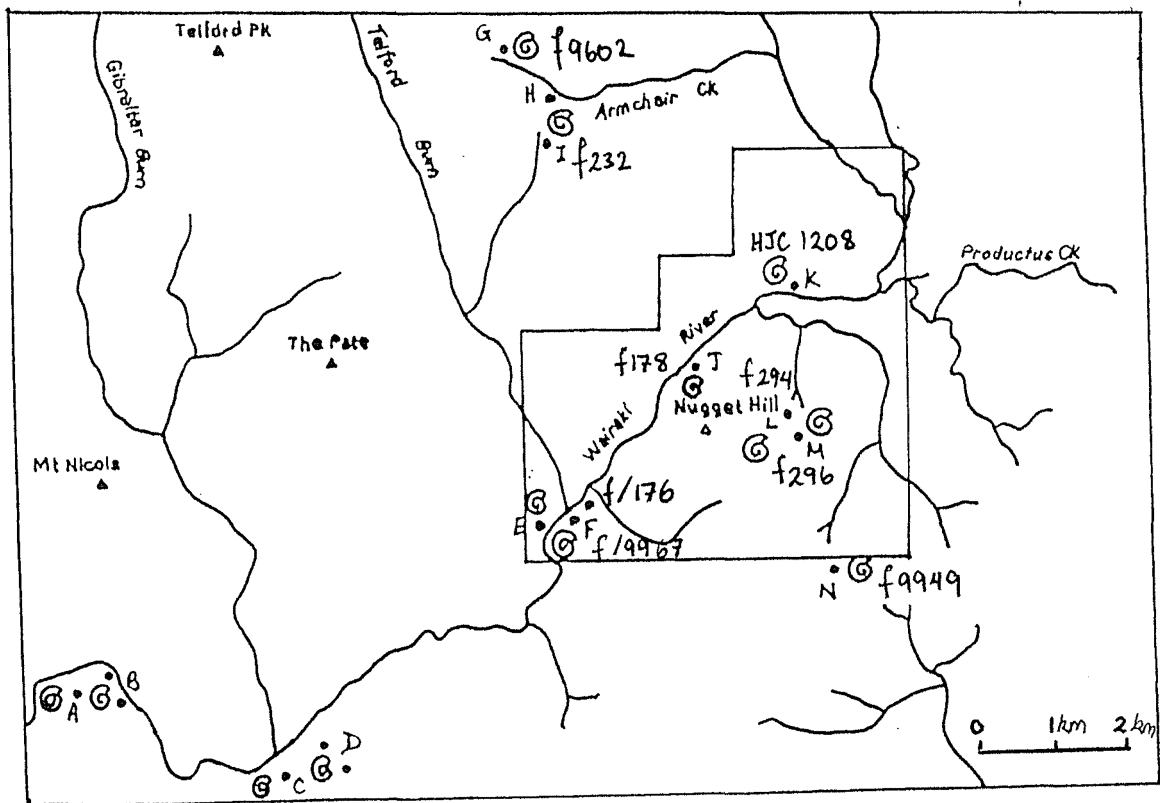
AGE OF THE TAKITIMU GROUP

The Takitimu Group as a whole is Early Permian in age (Waterhouse, 1958) and contains the type section for the Telfordian and Mangapirian Stages, the basal stages of the Permian of New Zealand as defined by Waterhouse (1967). The basal 600 m of this type section is unfossiliferous and may be partially Carboniferous in age (Houghton, 1981).

FOSSIL LOCALITIES

The fossil locality map of the Nugget Hill region and surrounding areas (Figure 2.31), shows the distribution of some of the more common fossils found previously in the Takitimu Group. These include; *Cladochonus sp.*, *Attenuatella*, and Atomodesmatinae including *Trabeculatra trabeculum* (Figure 2.32). Other fossils which have been found include; *Plekonella southlandensis*?, *Crinoidea*, wood, *Terebratuloida* and fish scales (*Acrolepididae*?) (H.J. Campbell, pers. comm. 1992).

not italics.



- A *Notostrophia zealandicus* (Waterhouse, 1980)
 B *Notostrophia homeri* (Waterhouse, 1980)
 C *Notostrophia homeri* & *Martinia adentata* (Waterhouse, 1980)
 D *Martinia adentata* (Waterhouse, 1980)
 E *Martinia* (Waterhouse, 1980)
 F *Attenuatella altilis* & Crinoidea (H.J. Campbell, pers. comm. 1992)
 G *Echinalosia prideri* (Waterhouse, 1980)
 H *Daonella* or *Halobia* (mixed specimens) (Waterhouse 1980)
 I *Attenuatella*, Atomodesmatinae (*Trabeculatia trabeculum*), wood, Crinoid, fish scales, & possibly *Plekonella southlandensis* (H.J. Campbell, pers. comm. 1992)
 J *Cladochonus* sp. (H.J. Campbell, pers. comm. 1992)
 K *Terebratuloid* (H.J. Campbell, pers. comm. 1992)
 L *Cladochonus* sp.
 M Brachiopods (unidentifiable)
 N *Echinalosia prideri* (Waterhouse, 1980)

Figure 2.31. Distribution of the fossil localities in the southern Takitimu Mountains and the Nugget Hill area.

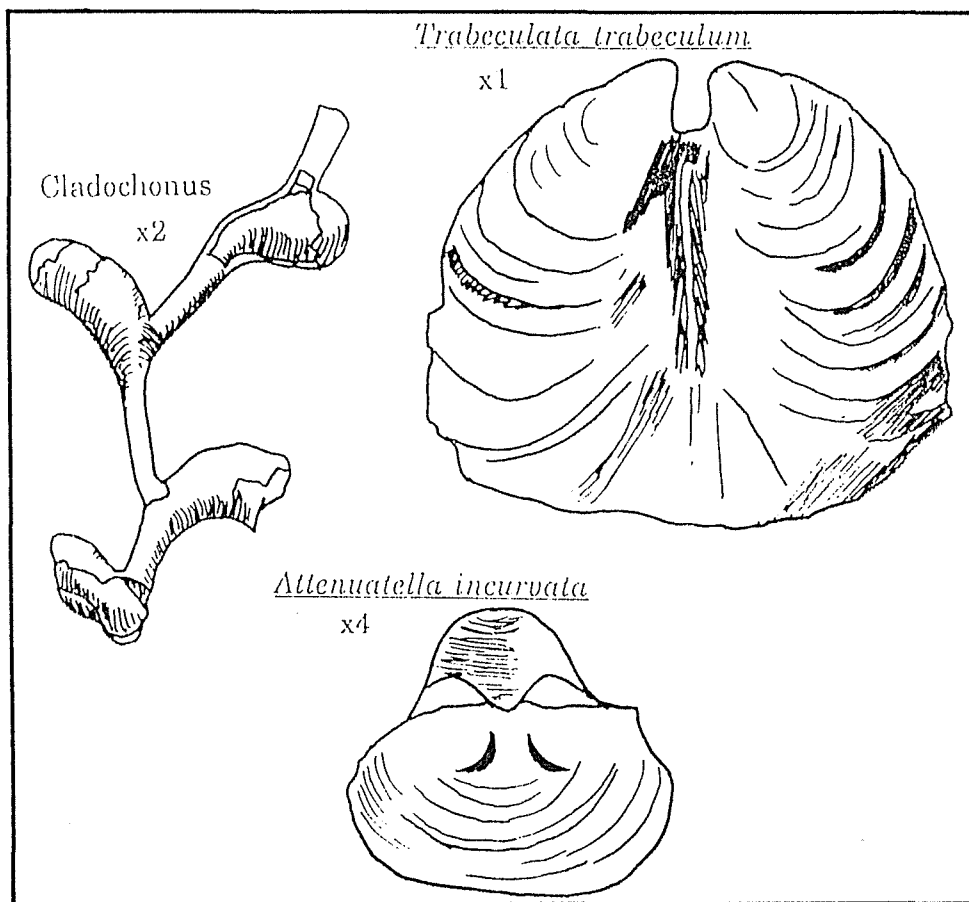


Figure 2.32. Representative diagrams of some of the fossil types found in the Nugget Hill area. (Teichert, 1981 and Speden & Keyes, 1981).

Fossils which I found include Cladochonus sp., (D44/f294) Atomodesmatinae (D44/f295), and a couple of brachiopods (D44/f296) (Appendix H). Atomodesmatinae fragments were found at two localities in the region (D44/133748 & D44/142753), mainly in fresh, dark grey, well sorted, fine grained lutite units. They generally occur in the rock as rectangular cavities, but sometimes still well preserved as thin tabloid prismatic fragments. A well preserved cast of half an Atomodesmatinid shell was found in grey mudstone, just south of the southern boundary of the mapped area. It was not however, good enough to be identified.

not itatics.

In contrast, all three of the brachiopod shells were found in an angular, very coarse volcanoclastic arenite deposit (D44/162759). The brachiopods are very small (1 cm diameter) and only leave sandstone moulds. No original shell material is preserved. They were not preserved well enough for an identification.

ENVIRONMENT OF DEPOSITION FOR THE TAKITIMU GROUP

The Takitimu Group consists predominantly of volcanic flows and pyroclastic and epiclastic rocks. Rapid changes in lithology occur along and across strike. Lava flows and pillow lavas dominate in the Heartbreak Formation (primary volcanics) and are interlayered within marine volcanoclastic rudites and arenite/lutite sequences in the MacLean Peaks Formation. Angular volcanogenic boulder rudites are likely to be products of Surtseyan to Strombolian type volcanism under very shallow marine to emergent conditions with some being redeposited by submarine sediment gravity flows.

The Heartbreak Formation is the only significant stratigraphic unit which formed close to a volcanic vent or vents.

Volcanism in and adjacent to the Takitimu sedimentary basin thus included 1) moderate to deep water extrusion of sheet and pillowed flows and deposition of hyaloclastite and 2) extrusive and explosive eruptions from shallow marine to marginally emergent volcanoes in, or on the margin of, the basin.

It is not clear from clast petrography which portion of the volcanogenic sediments were derived from subaerial sources and which portion from submarine. The localised regions of the red oxidation colouring of some of the lithologies combined with abundant plant material found in the central Takitimu Mountains suggests that at least some of the volcanic centers in this arc were subaerial, but there is direct evidence from primary volcanic flows that most other vents were clearly submarine.

The Takitimu arc/arc-basin setting formed a dynamic, closed sedimentary system in which large volumes of volcanoclastic material were generated at the arc and rapidly deposited in flanking basins. The system would have included mechanisms such as seismic shocks, magma movement deformation and rapid loading, for triggering mass flow events. A thick volcanoclastic apron prograded rapidly into the basins adjacent to the vents via channel and fan systems.

Chapter 3.

WHITE HILL INTRUSIVE SUITE

INTRODUCTION

The White Hill Intrusives are defined by Houghton (1986) as a suite of moderately to coarsely crystalline intrusive rocks of gabbroic to quartz dioritic composition which intrude the Takitimu Group in the central Takitimu Mountains. They are distinguished from the Takitimu Group lavas by their coarse grain size and ubiquitous fine-grained margins. Houghton (1986) also includes basaltic dikes, which crosscut the coarser intrusives, as being part of the White Hill Intrusive suite.

Due to poor exposure of the White Hill Intrusives in the Nugget Hill area however, no intrusive contacts have been observed. The White Hill Intrusive Suite in the Nugget Hill area was mapped using their relative freshness and hence resistance, cross-cutting relationships, geochemistry and their coarsely crystalline nature.

DISTRIBUTION AND FIELD DESCRIPTION

Intrusive bodies mapped in the Nugget Hill area may occur as concordant lensoid bodies (sills) or discordant dykes. Individual intrusions may extend along strike for >2.5 km and have widths ranging from 5 m to 150 m.

The degree of alteration of individual intrusions was a major factor in assigning lithologies which are present in both the Takitimu Group and the White Hill Intrusive Suite. When unweathered, White Hill Intrusive lithologies are tenacious and composed of a medium to coarse grained, equigranular rock consisting of plagioclase, pyroxene and opaques. Many of these rocks do however show higher degrees of alteration due to the influence^{of} low grade metamorphism.

PETROGRAPHY

The White Hill Intrusive Suite is characterised by simple mineralogy and widely varying grain size. Mineralogy is dominated by three mineral phases, plagioclase, augite and magnetite (Appendix A). Other phases include titanium-rich biotite (Cooper pers. comm. 1992) (Figure 3.1), zeolites, apatite, and olivine replacements such as chlorite and chlorite-vermiculite (Figure 3.2). The rocks also contain small amounts of prehnite, albite and carbonate.



Figure 3.1. Photomicrograph showing a grain of titanium rich biotite within a gabbroic rock of the White Hill Intrusive Suite (OU 63922). Magnification is x40.

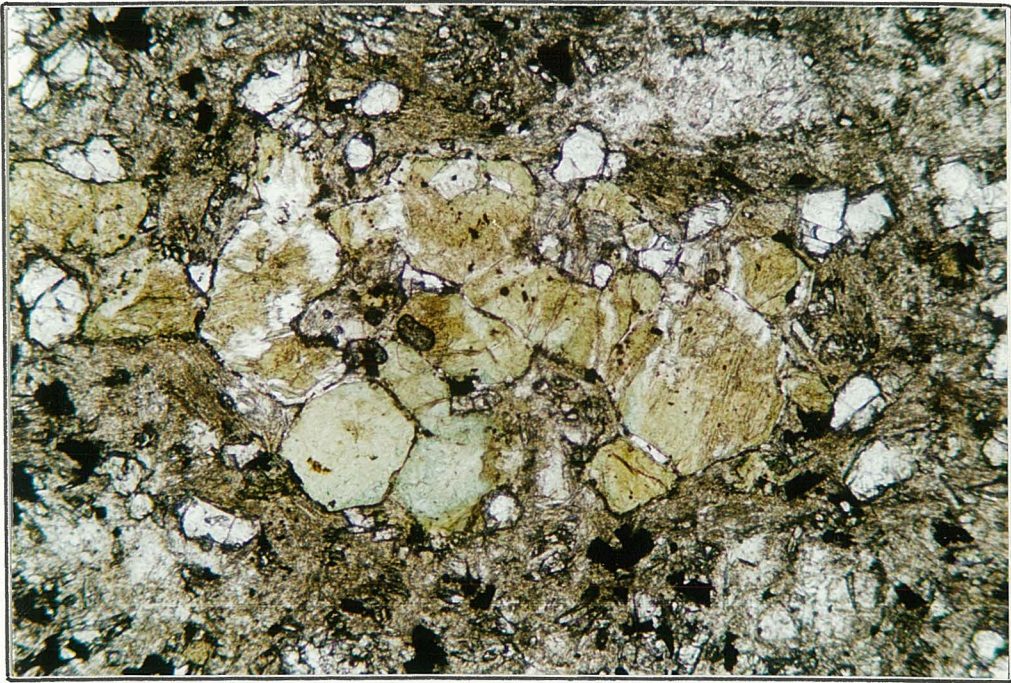


Figure 3.2. Photomicrograph of glomeroporphyritic olivine crystals replaced by chloritic minerals and celadonite (OU 63956). Magnification is x40.

Primary Mineralogy

Gabbros and microgabbros are the dominant lithologies of the White Hill Intrusive Suite in the Nugget Hill area. The mineralogy of both these lithologies is very similar and will be discussed inclusively.

Plagioclase

Plagioclase within the intrusives is invariably sericitised. This alteration seems to replace the plagioclase grain from the outer rim towards the centre. Some unusual plagioclase phenocrysts show sector zoning (Figure 3.3). Sericitisation often forms concentric zonal patterns of alteration within a plagioclase crystal, leaving a clean narrow rim. Compositions range from andesine to anorthite (Appendix C).

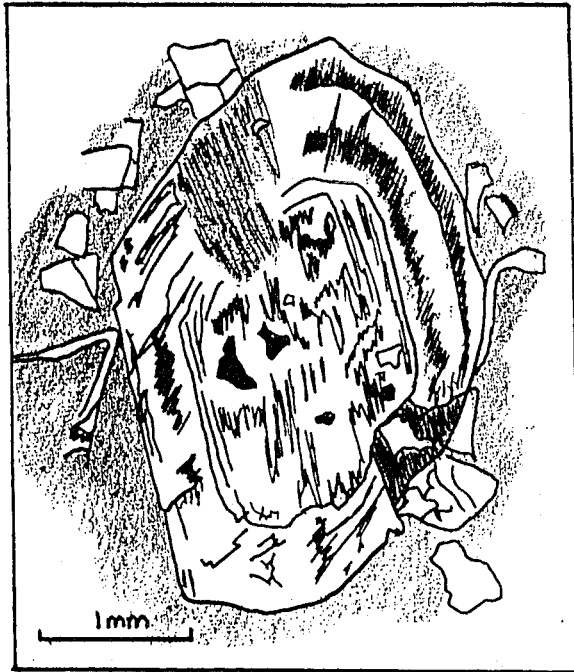


Figure 3.3. Sketch of a sector zoned plagioclase phenocryst in a White Hill Intrusive gabbro (OU 63918).

Clinopyroxene

Augite, the dominant clinopyroxene, occurs as subhedral, pale green crystals (Appendix C). All crystals show some degree of fracturing and some contain kink bands. A few grains contain replacement minerals such as chlorite or chlorite vermiculite. Many augite grains have magnetite in close association, in some cases magnetite occurs as sub-ophitic overgrowths. Micron sized inclusions of Mg-Fe rich hornblende (ferrohastingsite) have also been found (Table 3.14).

Magnetite

Phenocrysts of magnetite often show skeletal textures which are crystallographically controlled (Figure 3.4). These appear to be preferential resorption features.

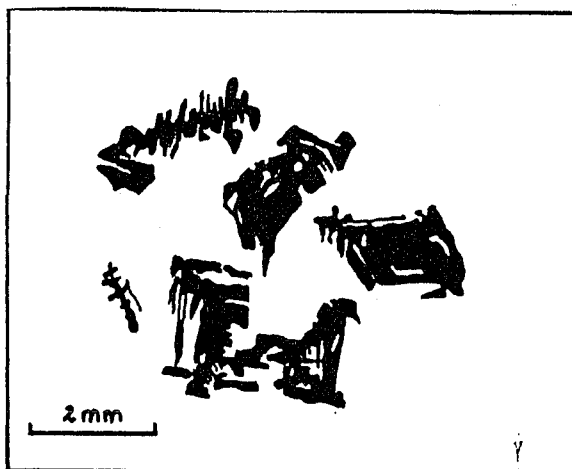


Figure 3.4. Sketched examples of skeletal magnetite phenocrysts in a microgabbro from the White Hill Intrusive Suite (OU 63920).

Hornblende

A single Fe-rich (Table 3.14) hornblende megacryst was found in sample OU 63923. The crystal has rounded edges and is surrounded by a 'halo' of fine grained pyroxene and magnetite (Figure 3.5).

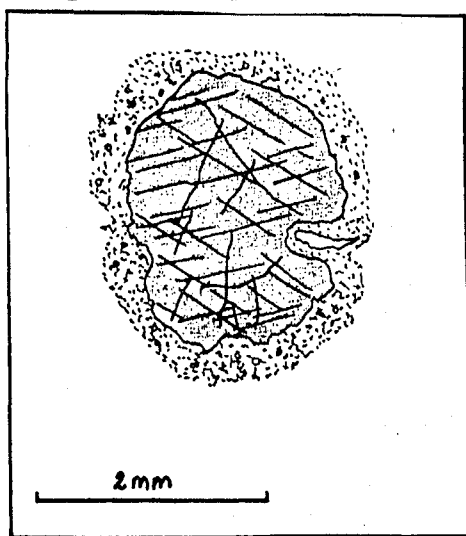


Figure 3.5. Sketch of the hornblende megacryst showing a very rounded perimeter circled by a resorption rim of fine magnetite and pyroxene crystals (OU 63922).

Apatite

Apatite crystals are scarcely visible, they form transparent acicular crystals in the matrix.

Titanium-rich Biotite

This dark reddish-orange biotite mineral (Figure 3.1) is very rare in the igneous rocks in this area. It occurs in only two samples, of relatively small amounts in both (microgabbros OU 63922 & OU 63921). The red-orange colouring was interpreted to result from higher than normal titanium contents (Cooper pers. comm. 1992).

Metamorphic Mineralogy

Zeolites

Zeolites found in the White Hill Intrusive rocks are dominated by laumontite, which may occur within veins (Figure 3.6) or as replacement minerals throughout the rock. Stilbite and analcime are also found but only in minor amounts (Chapter 5).



Figure 3.6. Photomicrograph of a laumontite crystals infilling a vein. Note the cruciform extinction pattern (OU 63919). Magnification is x40.

Prehnite

Prehnite is relatively rare in comparison with the zeolite minerals and was found to occur primarily in microscopic veins and in small clusters within the rock (Figure 3.7).

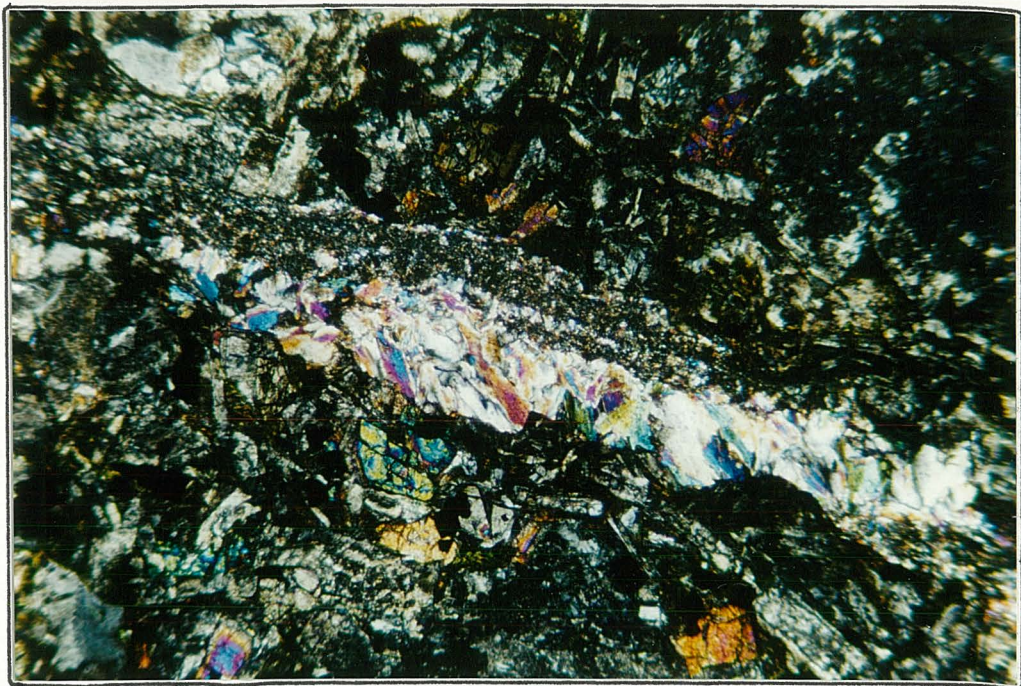


Figure 3.7. Photomicrograph showing a vein of prehnite in microgabbro from the White Hill Intrusive Suite (OU 63914). Magnification is x40.

Albite

Albite occurs as a secondary phase, forming rims around altered plagioclase grains and sometimes surrounds augite.

Alteration Products

Chlorite & Chlorite-vermiculite

Chlorite and chlorite-vermiculite are common in these rocks often in close association with zeolite mineralisation. They also occur in some rocks as pseudomorphs after olivine.

Carbonate

Carbonate is a very minor phase occurring very rarely in the groundmass or in some veins.

GEOCHEMISTRY

Major Elements

The White Hill Intrusives of the Nugget Hill area are plotted on major element Harker variation diagrams (Figure 3.8a-j & Appendix B). Houghton's (1986) White Hill Intrusive data is also plotted for comparison. The silica content of the White Hill Intrusive Suite in the Nugget Hill region ranges from 47.5 to 52.1 wt.%, considerably lower in SiO_2 than Takitimu Group volcanics. Within this range there seem to be two distinctive compositional groups with a gap (49.1-51.8 wt.% SiO_2) between the two. This gap corresponds with the gap in

arenite and igneous rocks of the Takitimu Group.

Geochemical trends of Nugget Hill White Hill Intrusives are very similar to those of the Takitimu Group volcanic lithologies (Chapter 2). Hence, they are also similar to Houghton's microcrystalline and porphyritic microcrystalline White Hill Intrusive Suite (Figure 3.8a-j).

High CaO and Al₂O₃ contents and low MgO and TiO₂ contents of the White Hill Intrusive Suite are, like the Takitimu Group volcanics, typical of calcalkaline island arc series (BVSP 1981 in Houghton, 1985).

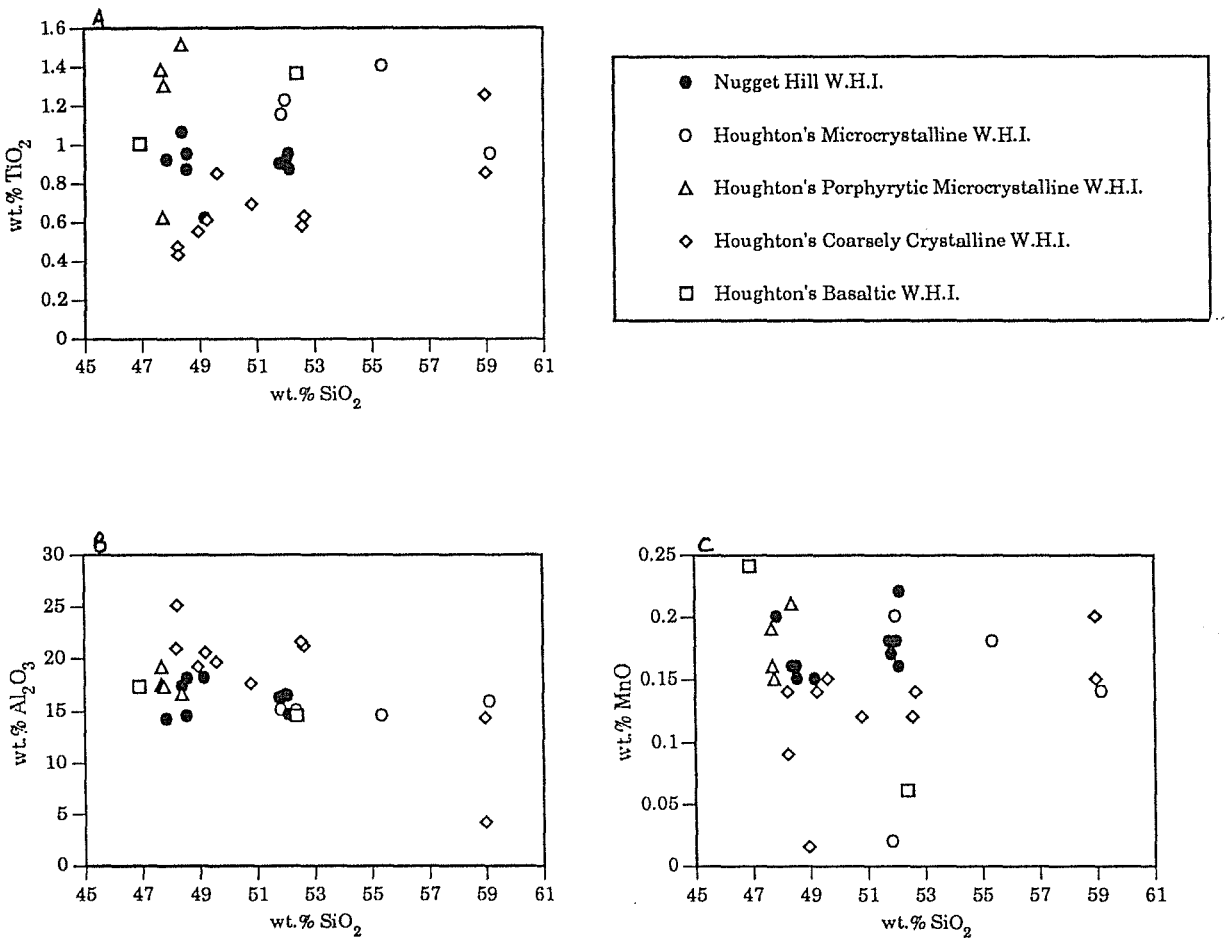


Figure 3.8. Harker variation diagrams for the White Hill Intrusive Suite in the Nugget Hill region compared with the White Hill Intrusive Suite in the central Takitimu Mountains (Houghton, 1985).

WHITE HILL INTRUSIVE SUITE

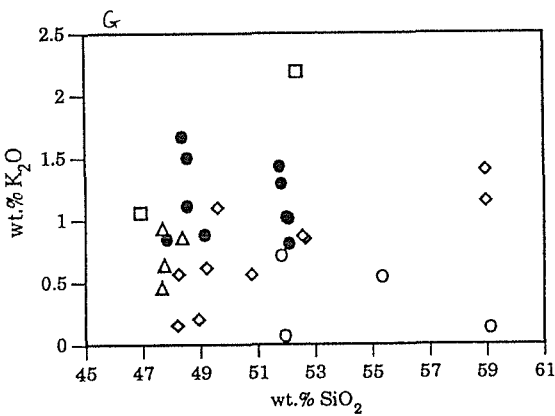
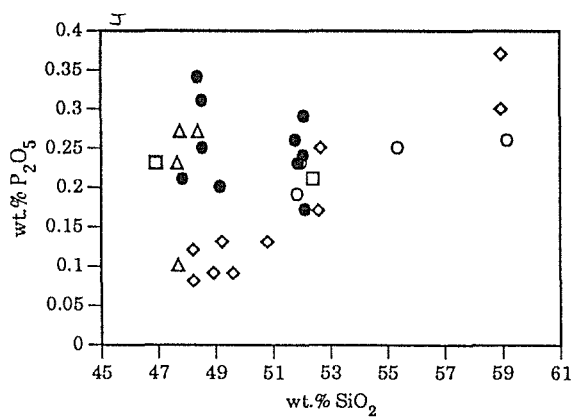
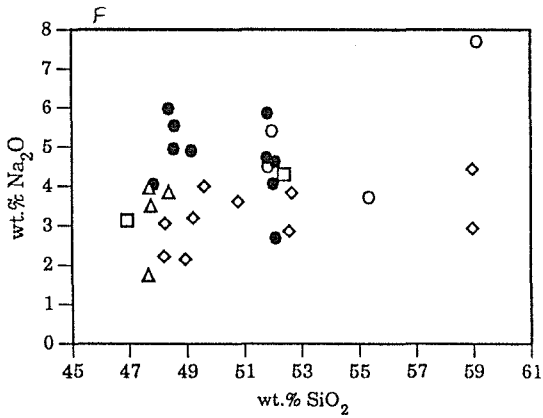
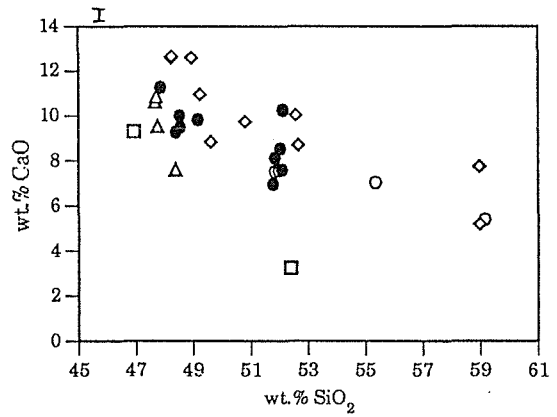
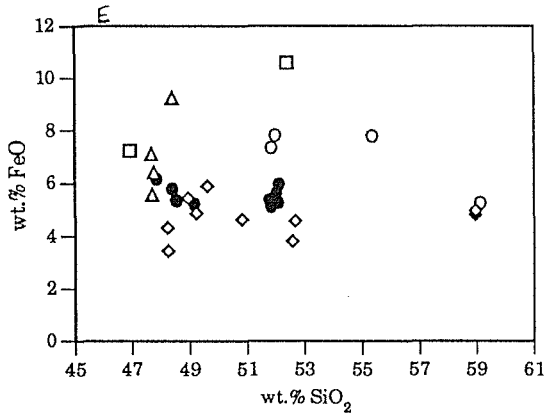
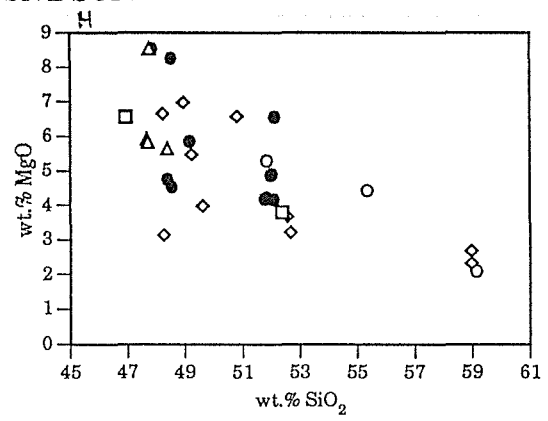
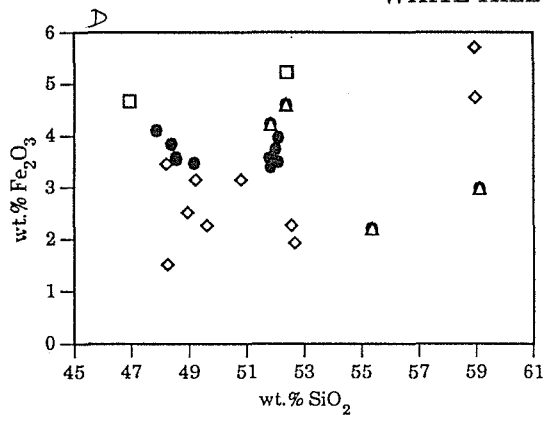


Figure 3.8 continued... Harker variation diagrams for the White Hill Intrusive Suite in the Nugget Hill region compared with the White Hill Intrusive Suite in the central Takitimu Mountains (Houghton, 1985).

Tectonomagmatic discrimination diagrams (Figure 3.9) show that the composition of the White Hill Intrusive magmas is comparable primarily to calc-alkaline basalts. They also plot near the island arc tholeiite field. In general the diagram indicates that the White Hill Intrusive Suite is chemically similar to Takitimu Group lavas and volcanoclastic sediments.

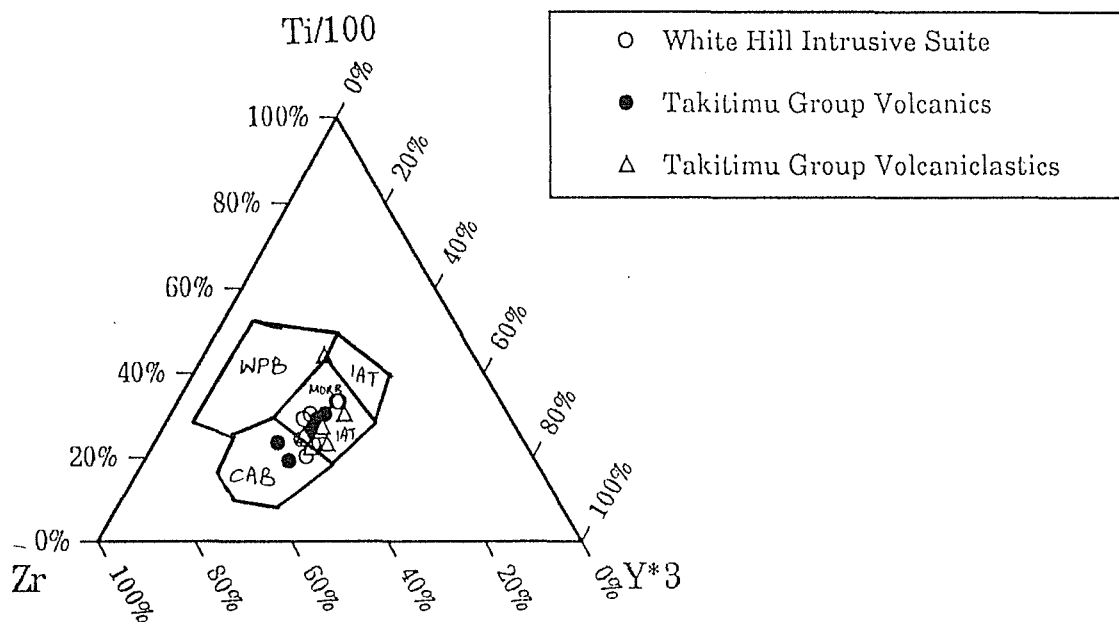


Figure 3.9. Distribution of analysed rocks of the White Hill Intrusive Suite in comparison with Takitimu Group lavas and volcanoclastics on a Ti/100-Zr-Y*3 tectonomagmatic discrimination diagram for oceanic basaltic rocks (after Wilson, 1989).

Plagioclase feldspar is the dominant phase in all the White Hill Intrusives. Anorthite content varies considerably (An_{35} - An_{91}) (Appendix C). Sample OU 63923 has Ca rich cores and rims, with core being only slightly higher in Ca (Appendix C). The majority of analyses have compositions An_{71-76} with the exception of an An_{35} core (OU 63916) and an An_{91} rim (OU 63917). Plagioclases in gabbros analysed by Houghton (1986) have anorthite contents of An_{80-70} . White Hill plagioclase analyses are generally more anorthitic than volcanic rocks of the Takitimu Group (Figure 3.10).

WHITE HILL INTRUSIVE SUITE

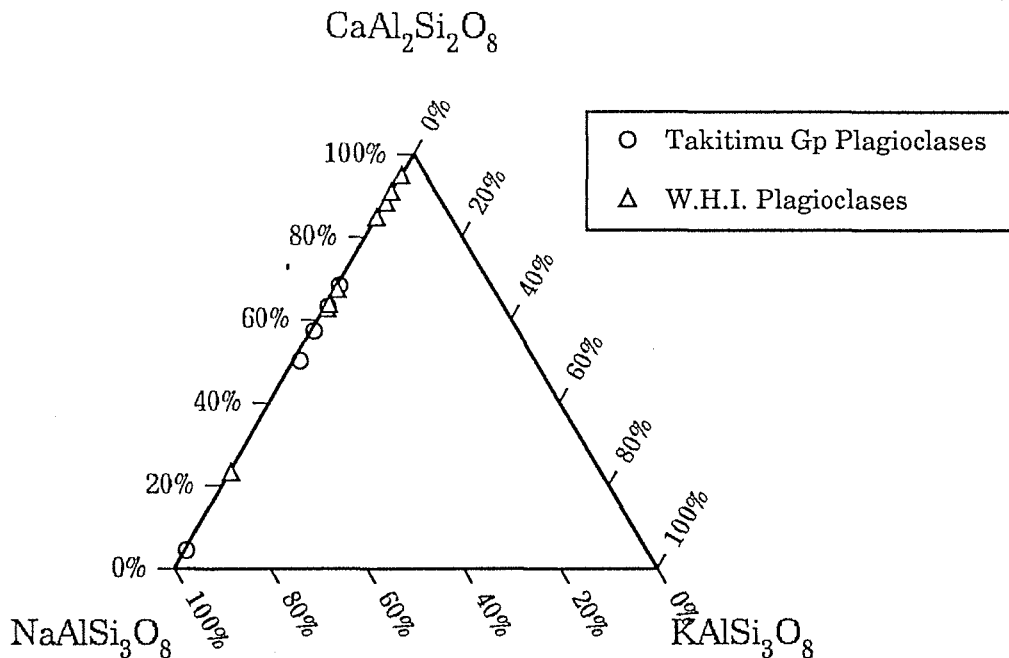


Figure 3.10. Analyses of plagioclase compositions for both the igneous rocks of the Takitimu Group and the White Hill Intrusive Suite plotted on a Ca-Na-K diagram.

Similar to Takitimu Group pyroxenes, Ca rich pyroxenes are ubiquitous in White Hill Intrusive rocks. As the Ca-Mg-Fe triangle shows (Figure 3.11) clinopyroxene analyses lie mainly within the Ca rich corner of the augite field with a few overlapping into the diopside field. There is no distinctive correlation between composition and core and rim of pyroxene phenocrysts except for some of the analyses which show a slight FeO increase (eg; OU 63918) in pyroxene rims (Appendix C). White Hill pyroxene analyses lie at the Mg rich end of the arcuate trend defined for White Hill Intrusive analyses by Houghton (1986).

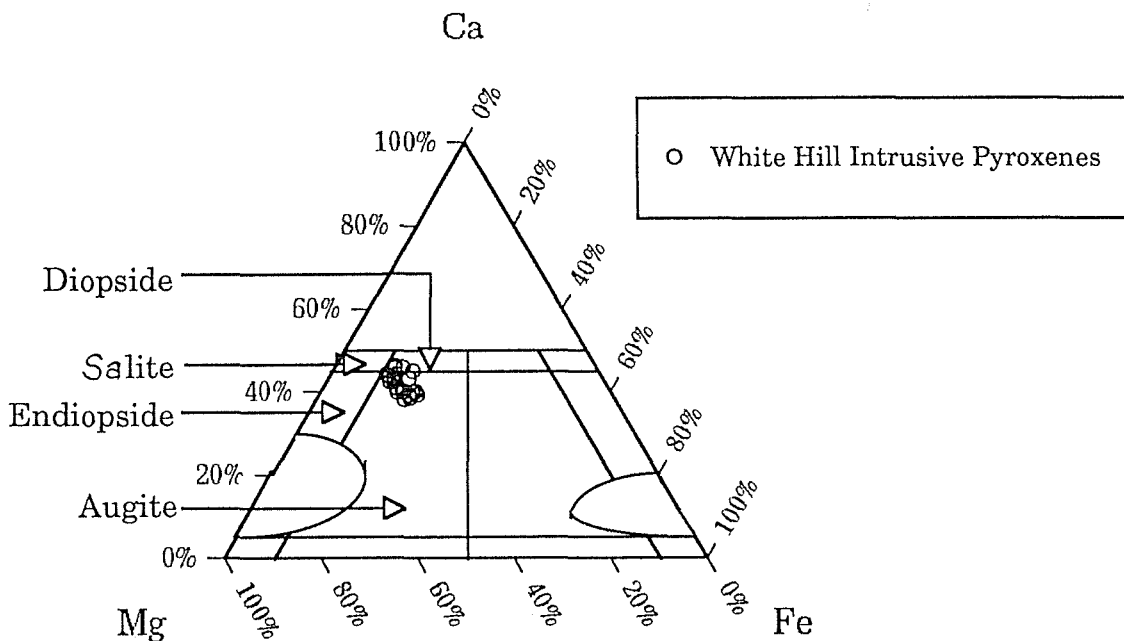


Table 3.11. White Hill Intrusive pyroxene analyses plotted on the Ca-Mg-Fe diagram.

Titanomagnetite is present in the groundmass of all samples and also may occur as phenocrysts in a few of the microgabbros. Titanomagnetite analyses are presented in Table 3.12. TiO_2 contents range from 8.2 to 14.2 wt.%. Low totals for some analyses may reflect the fact that the samples were not analysed for vanadium or other minor elements (Table 3.12).

WHITE HILL TITANOMAGNETITE COMPOSITIONS

	OU 63918	OU 63917	OU 63917	OU 63915
SiO ₂	0.18	0.19	0.59	0.00
Al ₂ O ₃	2.94	1.65	3.80	4.54
TiO ₂	8.16	14.18	9.79	8.42
FeO	79.49	76.66	77.98	82.65
MnO	0.98	3.11	0.54	0.47
MgO	0.62	0.00	1.17	2.96
CaO	0.19	0.06	0.09	0.02
Na ₂ O	0.13	0.00	0.00	0.00
K ₂ O	0.02	0.04	0.00	0.00
Cr ₂ O ₃	0.34	0.00	0.07	0.10
NiO	0.00	0.05	0.00	0.00
TOTAL	93.05	95.94	94.03	99.16
Cations on the bases of 32 oxygen atoms				
Si	0.07	0.07	0.21	0.00
Al	1.28	0.68	1.59	1.81
Ti	2.26	3.73	2.61	2.14
Fe	24.51	22.42	23.13	23.34
Mn	0.31	0.92	0.16	0.13
Mg	0.34	0.00	0.62	1.49
Ca	0.08	0.02	0.03	0.01
Na	0.09	0.00	0.00	0.00
K	0.01	0.02	0.00	0.00
Cr	0.10	0.00	0.02	0.03
Ni	0.00	0.01	0.00	0.00
Total	29.03	27.87	28.38	28.95

Table 3.12. Electron probe analyses of titanomagnetites in the White Hill Intrusive Suite.

The hornblende phenocryst within the porphyritic basalt (OU 63923) has a ferri-tschermakitic composition (Table 3.13). The core of the hornblende is slightly more enriched in Mg (15.15 wt.%) with respect to Fe (14.05 wt.%), whereas the rim contains Mg and Fe contents which are about the same (15.3 %). The outer rim had an Fe content of 13.2 % and an Mg content of 15.29 %, similar to the core (Table 3.13).

WHITE HILL INTRUSIVE SUITE			
AMPHIBOLE ANALYSES			
	White Hill Intrusive	Takitimu Group	
	OU 63918	OU 63923	OU 63923
	Inclusion	Rim	Core
SiO ₂	39.26	42.88	43.06
Al ₂ O ₃	15.37	12.98	12.89
TiO ₂	1.68	1.43	1.38
FeO	21.04	14.05	15.42
MnO	0.31	0.13	0.07
MgO	7.67	15.15	15.23
CaO	10.87	11.77	10.68
Na ₂ O	2.71	1.85	1.90
K ₂ O	0.17	0.39	0.33
Cr ₂ O ₃	0.00	0.00	0.03
NiO	0.00	0.00	0.00
TOTAL	99.08	100.63	101.01
Cations on the bases of 23 oxygen atoms			
Si	5.95	6.17	6.18
Al	2.74	2.20	2.18
Ti	0.19	0.15	0.15
Fe	2.66	1.69	1.85
Mn	0.04	0.02	0.01
Mg	1.73	3.25	3.26
Ca	1.76	1.81	1.64
Na	0.80	0.52	0.53
K	0.03	0.07	0.06
Cr	0.00	0.00	0.00
Ni	0.00	0.00	0.00
Total	15.91	15.87	15.87
CLASSIFICATION Ferrohastingsite Ferri-TschermakiteFerri-Tschermakite			

Table 3.13. Electron probe analyses of amphiboles in the White Hill Intrusive Suite.

The majority of the White Hill Intrusive samples with normative calculations (Appendix D) are nepheline normative with 6-15 % and are also olivine normative. No nepheline was observed in any of the White Hill Intrusive rocks, but olivine pseudomorphs are common. Otherwise normative calculations give very similar results to those of the Takitimu Group volcanics.

WHITE HILL INTRUSIVE SUITE

Trace Elements

(Table 3.14)

WHITE HILL INTRUSIVE TRACE ELEMENTS

	OU 63915	OU 63914	OU 63921	OU 63919	OU 63923	OU 63958	OU 63922	OU 63920	OU 63916	OU 63917	OU 63918
Pb	7	40	3	5	5	5	3	2	3	3	3
Ba	76	102	45	90	56	85	55	106	84	62	68
U	2	1	1	0	1	1	1	0	2	2	0
Th	2	1	1	0	1	0	0	1	2	1	0
Nd	18	20	18	22	12	12	18	24	18	18	16
Pr	10	7	6	6	7	14	6	5	6	6	8
Ce	21	17	10	36	12	9	15	34	13	15	21
La	8	8	7	12	5	3	7	17	5	8	7
Sr	927	562	698	935	466	334	687	983	515	338	543
Rb	21	25	16	31	15	17	18	32	24	12	15
Y	23	23	18	18	12	19	18	20	25	28	23
Th	2	1	1	0	1	0	0	1	2	1	0
Zr	107	101	54	85	38	71	57	86	102	121	98
Zn	77	68	55	55	54	52	59	55	53	66	64
Cu	151	108	86	164	56	101	104	147	23	105	103
Ni	16	16	59	37	34	78	56	35	25	43	18
Cr	38	15	245	34	60	274	246	28	45	91	22
V	264	217	232	311	279	258	241	369	235	265	231
Ga	21	20	18	19	19	16	13	21	18	23	20
Rb/Sr	0.023	0.044	0.023	0.033	0.032	0.051	0.026	0.033	0.047	0.036	0.028
V/Cr	6.9	14.5	0.9	9.1	4.7	0.9	1.0	13.2	5.2	2.9	10.5
V/Ni	16.5	13.6	3.9	8.4	8.2	3.3	4.3	10.5	9.4	6.2	12.8

Table 3.14. Trace element abundances (ppm) for the White Hill Intrusive Suite. For Trace element Harker diagrams refer back to Chapter 2, figure 2.31.

Pb, Ba, Sr and Rb contents are similar to those of the Takitimu Group volcanics with the exception of OU 63914 which has 40 ppm Pb, about 8 times the Pb content in the volcanics. The range in Ba (45-106 ppm) contents is not so broad in the White Hill Intrusives as it is in the volcanics (9-180 ppm). U and Th contents are very low comparable to those of Takitimu Group volcanics whereas Zn contents for both intrusives and extrusives are restricted to values of 52 to 77 ppm. Y contents range from 12 to 28 ppm, a narrower range again compared to that of the volcanics. Three White Hill analyses (OU 63921, OU 63922 & OU 63958) in particular contain quite high Cr (245-274 ppm) and Ni (56-78 ppm) contents. These three samples were collected along the length of the largest White Hill Intrusive sill in the region (D44/153783, D44/156772 & D44/162755).

The general decrease in nickel contents (Figure 2.29e) from the White Hill Intrusive analyses to Takitimu Group volcanic analyses suggests progressive olivine fractionation and the general decrease in Cr (Figure 2.29f) may suggest clinopyroxene fractionation (Wilson, 1989).

LAYERED WHITE HILL INTRUSION

Field Description of the Layered Intrusion

At a locality on the true left of the Wairaki River, just northeast of the Telford/Wairaki River confluence (D44/1337485), there is a sequence of layered rocks which superficially resembles a sedimentary sequence. Close inspection reveals that these rocks have an igneous texture and are in fact microgabbros which are part of a layered intrusive body striking subparallel to the river and dipping into the bank ($098^{\circ}/35^{\circ}\text{S}$) (Figure 3.15).



Figure 3.15. Photograph showing five of the layered units of the Layered White Hill Intrusion located on the true left of the Wairaki River (D44/1337485).

The same layers crop out on the opposite side of the river, where they have the same attitude. This sequence of intruded microgabbros is concordant with the overlying volcanoclastic and volcanic lithologies of the Takitimu Group mapped to the southeast (Figure 3.16). However no contacts were observed between the intrusive and any other unit.

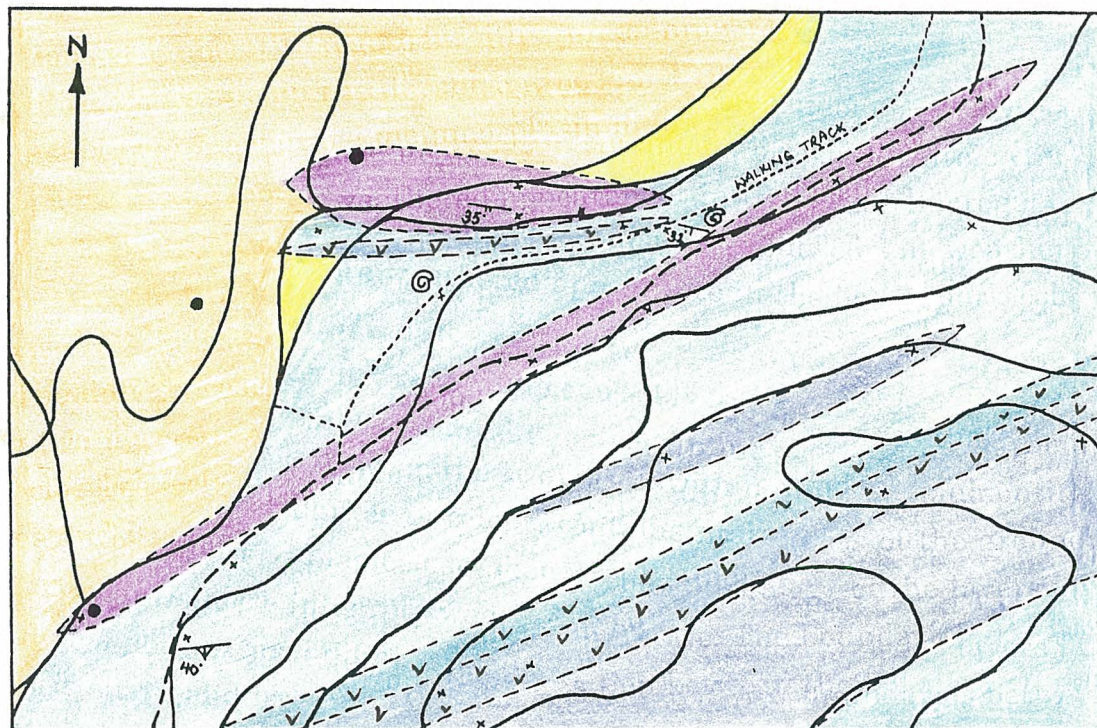


Figure 3.16. Detailed map showing the relationships of two White Hill Intrusive bodies with surrounding volcanic and volcanoclastic deposits. Note the relative concordance of both intrusions. The northern most purple body is that of the layered White Hill Intrusion (D44/1337485). (FOR LEGEND SEE MAP.)

The layering consists of repeated units of two different lithologies. The basal half of each unit is composed of light coloured, fresh layers, these pale grey layers grade up into darker layers which appear to be, from its weathered appearance, coarser (petrographically is not significantly coarser). At the top of each unit the dark layer is separated from the next light layer by an irregular, but well defined boundary. There are about seven repeating units visible at this locality, each unit being about 30 cm thick.

Petrography

In thin-section the distinction, between the two lithologies, is not obvious. The dark layer is slightly coarser (1.1 mm) than the light layer (0.9 mm) and it contains a higher concentration of coarse plagioclase phenocrysts. Pyroxene and skeletal magnetite phenocrysts are also present but in less abundance than some of the other White Hill Intrusives in the area. Phenocrysts within the light coloured layer are not so densely packed. The groundmass phase (avg grain size, 0.1 mm) occurs in both layers but are a lot more abundant in the lighter layer. It consists of acicular plagioclase laths (0.1 mm), sub-anhedral augite crystals and acicular magnetite crystals.

Chlorite is an abundant alteration in rock types of both layers and occurs as an interstitial phase in the groundmass of the lighter microgabbro. The

chlorite in both light and dark rocks, in places, pseudomorphs olivine. High proportions of laumontite together with a green-brown pleochroic chlorite-vermiculite occurs within the darker but not in the lighter microgabbro. A combined effect of low grade metamorphism and subsequent weathering could be the cause of the more weathered appearance in the basal, dark coloured layer.

Discussion

The differences between the two layers within each unit is that the upper of the two layers is darker in colour, contains more abundant laumontite, has more closely packed plagioclase phenocrysts, contains less of the groundmass phases and is more intensely weathered. The mineralogy of the layers is identical and textural differences are very subtle. The boundaries between each unit is sharp and irregular but the transition between the two layers within each unit is gradational.

The lack of laumontite in the lighter layers may reflect horizons of lower permeability and the fact that the darker layers are much more highly altered suggests that these represent bands of higher permeability. Perhaps the darker layers contained a phase such as glass or olivine which are more easily altered. Unfortunately there are no petrological clues as to what the original phase may have been.

The relationship between the two layers within each unit remain unclear and whether or not each unit represents repeated injections of magma can only be speculated.

The coarse grained nature of this body indicates that it is an intrusion, and its concordant relationship with overlying sediments indicates that it is a sill. The absence of visible contacts (the presence or absence of chilled margins in particular and baking of surrounding sediments) make it impossible to determine whether the sill intruded the sediments while they were still hot or cold.

RELATIVE AGES OF THE WHITE HILL INTRUSIVE SUITE

Whole rock samples of the White Hill Intrusive Suite, like the Permian Takitimu lavas give Jurassic-Triassic (215-220 Ma) K-Ar ages reflecting age of uplift (Houghton, 1977 in Houghton, 1986 p.160). Other evidence implies that most, if not all, of the intrusive rocks were emplaced in Late Permian time. That is, K/Ar ages of 231-242 Ma (Early Triassic) have been determined on

hornblende concentrates from Mackinnon Peak Intrusives which cross cut the Takitimu Group and the White Hill Intrusives (Houghton, 1977). This limited age data suggest the intrusives were emplaced shortly after, and possibly overlapping with, the closing stages of Takitimu volcanism (Houghton, 1986).

POSSIBLE CORRELATIONS

The White Hill Intrusive suite ^{may} ~~is~~ possibly be correlated with the Longwood Complex and Mackay Intrusives, to the south and north respectively. These correlations are based primarily on the similar lithologies of the intrusives.

K/Ar dates for the age of the Longwood Complex range from 133-188 Ma (Devereux et. al. 1968) and the Mackay Intrusives have been K/Ar dated as 208-180 Ma (Williams & Harper 1978). A 230 Ma Rb/Sr isochron for the Mistake Diorite which is within the Mackay Intrusives ^{was} ~~is~~ reported by Blattner & Williams (1991).

White Hill Intrusives and the lavas of the Takitimu Group are sufficiently similar in chemistry and mineralogy to suggest that they originated under similar conditions. In mapping the 14 km thick pile of Takitimu Group rocks Houghton (1977) describes an increase in thickness and grain size of the White Hill Intrusive Suite from east to west. That is, the volume of intruded magmas decreases within shallower levels of the Takitimu volcanic pile.

The similarities in chemistry and mineralogy, combined with close field associations between the intrusive suite and the Takitimu Group, suggest they were probably comagmatic. The suite is interpreted here as a shallow subvolcanic intrusive suite which tapped the same magma source as the Takitimu lavas (Houghton, 1986).

Houghton (1986) proposed a model where-by a thick volcanic/volcaniclastic apron was deposited at rates of about 1 m per 1000 years during Takitimu volcanism. As the volcanic pile grew, progressively more magma was intruded into the pile along bedding/flow planes, rather than being vented at the surface, and differentiated in a similar fashion to the Takitimu volcanic rocks (Houghton, 1986).

Chapter 4.

BARRETT'S FORMATION

INTRODUCTION

The Barretts Formation was first noted, in the Productus Creek area by Landis in 1984-85 (Landis pers. comm. 1992), as Jurassic conglomerates and sandstones comprising mainly of igneous clasts, particularly of granitoids and volcanics which rest unconformably on Takitimu and Productus Creek Groups (Landis pers. comm. 1992).

Rocks of the Barretts Formation were first recognised in the Wairaki River area by Aslund (1988). However her mapping fails to show the full extent of the formation in this area. Mapping carried out for this study reveals more extensive outcrop of the Barretts Formation in the region to the north and south of the Wairaki River (northeast corner of Map). In this area, Aslund mapped the Barretts Formation as alluvium.

Some of the conglomerates in formations mapped previously, such as the "Permian" Letham, Hawtel, Elsdun, Mangarewa Formations and the "Triassic" Franklin Formation of the Murihiku Supergroup (Mutch 1972) were subsequently found to belong to the Barretts Formation (Landis, (1987); Aslund, (1988); Willsman, (1990)). It wasn't until clasts from these formations were dated that it was realised that these units couldn't be Permian (Landis et al. 1986).

The Barretts Formation has been found unconformably overlying the Permian Takitimu and Productus Creek Groups, and to be lying structurally beneath the Murihiku Supergroup. The Wairaki Melange which occurs between the Murihiku Supergroup and the Barretts Formation is thought to be associated with the reverse faulting on the Letham Ridge Thrust.

LITHOLOGIES

The Barretts Formation, northeast of Nugget Hill, is composed of fine sandstones, coarse sandstones, carbonaceous sandstones and clast supported conglomerates of varying clast size.

At D44/155785 the base of a Barretts outcrop is dominated by a coarse, bouldery (some as large as 30 cm diameter) to cobble conglomerate which is overlain by a pebbly layer, 3 m thick (Figure 4.1). Towards the top of this layer

the pebbles become much more highly cemented and form a resistant cap which protrudes out above the other layers.

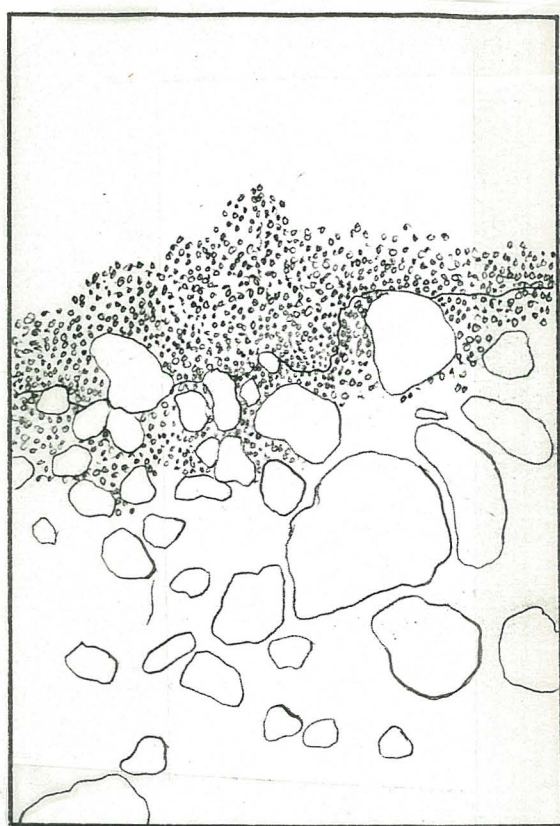


Figure 4.1. Photograph and overlay showing an irregular contact between a boulder conglomerate and pebble conglomerate of the Barretts Formation (D44/160787). The compass is 10 cm long.

Further to the west, at a higher elevation than conglomerates at D44/158785, the Barretts grades up into coarse sandstones which are interbedded with granule bands a few centimeters thick (Figure 4.2). Other Barretts localities consist of finer grained sands which contain abundant carbonaceous material (eg; D44/167782).



Figure 4.2. Photograph of interbedded granular beds within sandstone beds of the Barretts Formation. The dark bands at the top and bottom of each granular layer consists of concentrations of angular magnetite grains. Note the large well rounded granitic clast in the bottom right of the sample.

DISTRIBUTION & DESCRIPTION

In the Nugget Hill area the Barretts Formation occurs only in the farthest north-eastern corner of the map. An angular unconformity exists between steeply dipping Takitimu Group, and gently dipping Barretts Formation.

Due to the predominantly granitic and silicic composition of clasts in the Barretts Formation, occurrences in the field are relatively easy to locate, in that it is the only formation in the area which contains these exotic lithologies in comparison with lithologies found in the Takitimu Group.

The best exposures occur in the Wairaki River and in streams draining the surrounding hills. Although on the tops of the rolling hills in this area, Barretts can be mapped using the distribution of remnant "ducks egg", shape

and sized, silicic igneous cobbles. These cobbles tend to lie on top of the surface in bare patches of sparse vegetation.

Although the contact between the Takitimu Group and the Barretts is rarely exposed, the contact can usually be estimated between closely spaced outcrops of the two formations. The contact can be observed at a locality on the true left of the Wairaki River (D44/169778), only when the river is low. The Barretts conglomerate here consists of coarse cobbles grading up into a horizon of pebbles which are set in an orange weathered matrix. Above the pebbly layer the clast sizes coarsen and towards the top of the bank there is a fine grained micaceous layer (Figure 4.3).



Figure 4.3. Photograph and overlay showing an irregular contact between arenites of the MacLean Peaks Formation (Takitimu Group) and cobble conglomerate grading into pebble conglomerate (orange) of the Barretts Formation (D44/169778). The lecture pad is 36 cm long.

At this locality there are also four large pieces of wood which are silicified and cemented into the surrounding conglomerate (Figure 4.4). A very tentative paleocurrent vector was estimated from the general alignment of these logs, assuming flow was parallel to the logs (ie; their *plunge/trend* is approximately $008^{\circ}/106^{\circ}$).



Figure 4.4a & b. a) Photograph showing the largest (90 cm) of the fossilised wood found in cobble conglomerate of the Barretts Formation (D44/169778). b) Photograph showing three pieces of fossilised wood in cobble conglomerate of the Barretts Formation (D44/169778).

The Barretts Formation is not only distinctive in that it contains granites in the coarser conglomerates, but also because of its high mica content. The finer grained carbonaceous material also makes it easier to distinguish in outcrop. The softer nature of the Barretts sands in comparison with Takitimu Group sandstones is another useful criterion used in Barretts identification.

BARRETT'S SANDSTONES

In outcrop, sandstones of the Barretts Formation are variable in that in some places they are soft and very poorly indurated, and in others they tend to be relatively hard and well indurated. It is the finer, carbonaceous sandstones which are less indurated and the cleaner, coarse sandstones which are consolidated. Hence, due to poor outcrop of the softer material and good outcrop of the indurated sands, bedding and other sedimentary structures were only observed within the latter. Unfortunately no fossils were found in these sandstones but molluscs have been found on a ridge north of Productus Creek (D44/191789) by geologists on the 1987 Geological Society field excursion.

Structures seen in Barretts sandstones at D44/155785 include laminations, bedding (089°/16°N) and normal graded beds (Figure 4.2). Graded structures give younging directions towards the north.

Modal Analyses & Petrography

Point counted sandstones from the Barretts Formation in the Nugget Hill area have Q:F:L compositions of 41:39:20 and 38:41:21 (quartzofeldspathic) (Chapter 2, Figure 2.27). Aslund (1988) and Willsman (1990) obtained compositions ranging from quartzofeldspathic (34:43:23 and 37:34:29 respectively) to lithic-rich/quartz poor (3:35:62 and 7:33:60 respectively) (Appendix E).

Point counting results from this study are plotted on two pie charts shown in figure 4.5. The dominant clast components are monocrystalline quartz, and opaques. However components such as potassium feldspar plutonic lithics, biotite and muscovite which are not found in arenites of the Takitimu Group are found in relative abundance within sandstones of the Barretts Formation. Limonite alteration is abundant throughout Barretts sandstones.

Pie Plots of Point Count Data for
Sandstones of the Barretts Formation

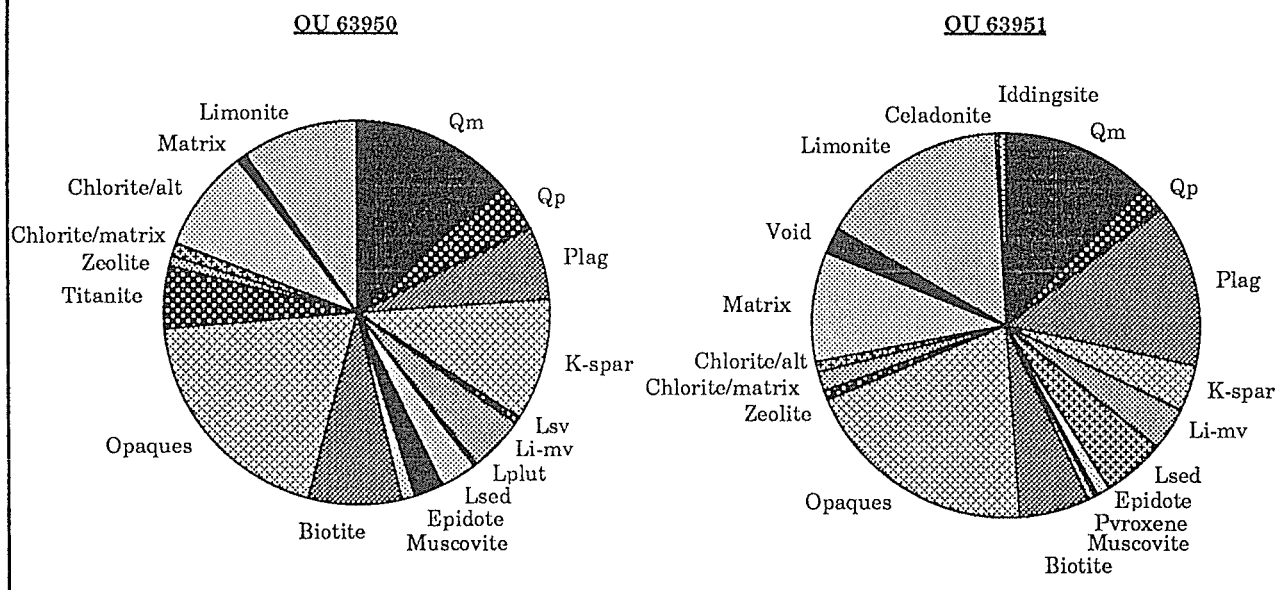


Figure 4.5. Pie Plots of point count data for two sandstone samples from the Barretts Formation.

Petrographic Description

Specimen No: OU 63950

Grid Reference: D44/157787

Macroscopic Description:

The grain size of the various sandstone beds range from fine sand to granules. The fine, medium and coarse sandstone beds are very well sorted, whereas the granular beds are poor to moderately well sorted. One granular sample contains a rounded clast about 1 cm in diameter (Figure 4.2). Medium to coarse sand beds which are light brown in colour often contain very thin bands of black magnetite grains which have been concentrated repeatedly throughout lamination horizons. Sandstones at this locality are also interbedded and consist of rounded to sub-rounded granitic and silicic igneous granules. ~~Sometimes~~ ^{sometimes} thinner sand lenses occur within the granule layers.

Microscopic Description:

In thin section, Barretts sands are angular to sub-angular whereas the granules tend to be well-rounded. The thin opaque bands consist of very angular magnetite grains. Magnetites are the dominant opaque minerals in the sandstones of the Barretts Formation. Monocrystalline quartz is the next most abundant mineral followed by alkali feldspar. Other major constituents include polycrystalline quartz, plagioclase, intermediate-mafic volcanic lithic

fragments, sedimentary lithic fragments, biotite, muscovite, smectite, chlorite and epidote (Figure 4.6).



Figure 4.6. Microphotograph showing the abundance of quartz and biotite with a lithic sandstone of the Barretts Formation (OU 63951). Magnification is x100.

Brief Description of Constituent Minerals:

Opagues (19%) are dominated by magnetite and are usually concentrated together forming thin bands.

Quartz (18%) is divided into two categories namely monocrystalline (14%) and polycrystalline (4%).

Feldspars (16%) which are present include both plagioclase (6%) and alkali feldspar (10%). Feldspar is commonly zeolitised and/or albitised and occasionally sericitised.

Micas (9%) are dominated by biotite (8%), but muscovite (1%) is also present in minor amounts. They often form long fibrous flexible crystals which are tapered at the ends (Figure 4.6).

Epidote (2%) is generally clear or very pale green/yellow, and is found as very small grains.

Smectite & Chlorite (20%) occur as secondary minerals, they are both found replacing the groundmass in volcanic lithic types.

Lithics (8%) present include porphyritic basalt-andesite volcanics (5%) and sediments (3%).

BARRETTS CONGLOMERATES

Conglomerates are predominantly clast-supported, with well rounded clasts of boulder, cobble and pebble size. Boulder conglomerates are rarer and only two clasts of about 30 cm across were found. Cobble and pebble conglomerates dominate. (Fig. 4.1)

Conglomerates at most localities are well rounded and very well cemented. They are characterised by large proportions of silicic volcanic clasts, and smaller numbers of basalt-andesite and plutonic clasts. Ignimbrite clasts were also found along the road side above outcropping Barretts conglomerates (D44/166776). Selected samples, including granites, a silicic porphyritic volcanic and two zeolitised volcanic clasts are shown in figure 4.7.



Figure 4.7. Photograph of selected clast samples from the Barretts Formation. From top left going clockwise there is a Orthoclase-muscovite granite, altered andesitic clast, silicic volcanic, mafic volcanic and a coarse biotite granite.

Volcanic clasts

Dacites and rhyolites dominate volcanic clasts. Intermediate and mafic clasts of basaltic and andesitic volcanics are also abundant. The volcanic clasts look to be derived from rocks of the Takitimu Group because the major constituents include augite, plagioclase and magnetite.

Plutonic clasts

Plutonic clasts present in the conglomerates include coarse biotite granites which contain approximately equal proportions of alkali feldspar and plagioclase. Orthoclase-muscovite granite is also present. Mineralogy suggests they are acidic, I-type, magnetite-series granites

Ignimbrite clasts

Ignimbrite clasts are rare in the majority of Barretts conglomerates. Several cobbles and one boulder was found at D44/166776. They are characteristic in that they have a welded texture of lensoid feldspar bodies surrounded by a felsitic groundmass (Figure 4.8).

However other more exotic metamorphic clasts have been reported such as an amphibolite metabasite which was described by Aslund (1988).

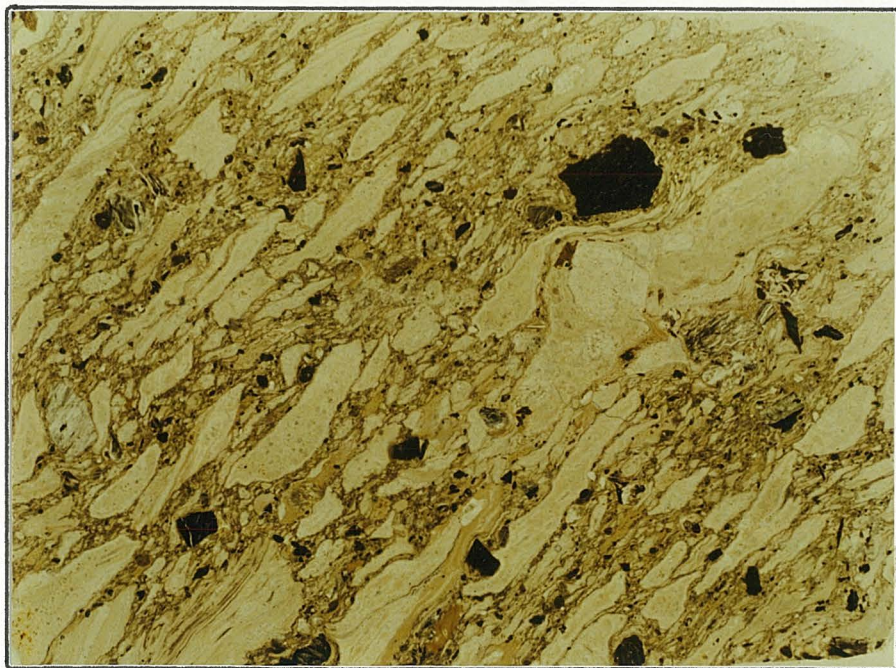


Figure 4.8. An enlarged (x4) photograph of an ignimbrite clast which is thought to have eroded from the Barretts Formation (OU 63952).

AGE OF THE BARRETTS FORMATION

Granite boulders, which were previously thought to be in the Productus Creek Group, were dated by Kimbrough, using U-Pb dating techniques. He obtained ages for boulders in the Lower Barretts of 214-220, 193-198, and 205 Ma and dates of 235-243 Ma for boulders in the Upper Barretts. Hence the Barretts

Formation is Jurassic or younger in age. Carbonaceous sediments were palynologically dated by Dr I. Raine (D.S.I.R) (Willsman, 1990). These palynoflora and rare marine molluscan fossils also indicate Jurassic ages for part of the formation.

ENVIRONMENT OF DEPOSITION & PROVENANCE

Only the S-type granitoid components of the Barretts Formation strictly imply a continental plutonic source. Other granitoid types may be indicative of a continental or a non-continental setting.

Sedimentary structures, such as graded beds, imbrication, laminations, abundant plant and wood debris and coarse grain size, observed in Barretts sandstones, suggest deposition within a dynamic fluvial setting. The presence of marine fossils found in other areas implies a marine influence for part of the formation. Plant fragments may indicate a non-marine or a nearshore environment of deposition. Large boulders within the Barretts conglomerates may have been derived, from a source in close proximity, with high energy rivers draining it, or perhaps by glacial rafting. The well rounded nature of many of the huge boulders point towards a high energy environment. Deposition of this formation probably occurred in close proximity to a margin of a continental source.

"All broad major lithological groupings represented by clasts in the Barretts Formation (and Murihiku Supergroup) conglomerates are known to occur within, and thus could conceivably have been derived from, geological units known or inferred to be of pre-Cretaceous age lying between the Grebe Fault and its analogues and the Murihiku Supergroup" (Powell, 1992).

Chapter 5.

METAMORPHISM & ALTERATION

INTRODUCTION

The rocks of the Nugget Hill area have undergone episodes of low grade metamorphism and surficial weathering. The situation is simplified by looking at the metamorphic minerals separately to weathering minerals. Little pervasive deformation is observed, with narrow (10 cm wide), widely spaced shear zones and veining being the dominant features present.

Metamorphic facies present in the Nugget Hill region include the zeolite and prehnite-pumpellyite facies (pumpellyite was not observed). Metamorphic minerals recorded in samples collected include prehnite, laumontite, thomsonite, heulandite, stilbite, mordenite (Appendix G), gonnardite (assoc. with thomsonite in thin-section) and analcime (Appendix F) (Figure 5.1a-f).

Chlorite, chlorite-vermiculite, calcite (Figure 5.1g), celadonite, quartz and limonite occur as weathering alteration products throughout the majority of samples. Although I refer to chlorite, chlorite-vermiculite etc... as alteration products I am not able to distinguish between minerals produced during metamorphism and minerals produced during weathering. The minerals which are referred to as alteration or weathering products are minerals which occur throughout a large proportion of the rocks in the region, that is they are not easily mapable, unlike the "metamorphic" minerals.

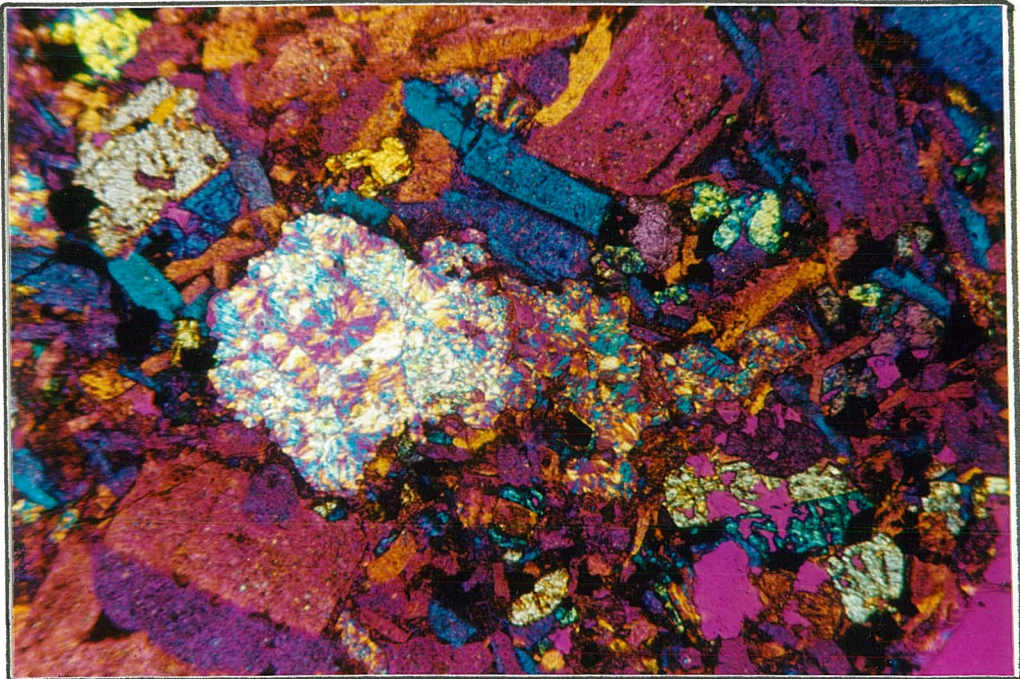
Originally porous volcanoclastic rocks and vesiculated volcanic rocks have been infilled by hydrated calcium aluminosilicates, calcite and quartz. Pervasive fractures and veining are also filled by many of the above metamorphic minerals. Very rare zones of impermeable glass associated with basaltic lavas are devoid of metamorphic mineralisation (Figure 5.1h).

METAMORPHIC ZONES

In order to understand the relationship between lithology and secondary mineral formation, I have compared the distribution of the various metamorphic minerals with the lithologies within which they are present. The mode of mineralisation can be established in terms of where the mineralisation occurs, eg; within the rock or forming vein systems.



A



B

Figure 5.1 a & b. Photomicrograph with (b) and without (a) a sensitive tint plate, showing the length fast nature of prehnite and the length slow nature of chlorite, both infilling the same amygdale within a basaltic-andesite (OU 63972). Magnification is x40.

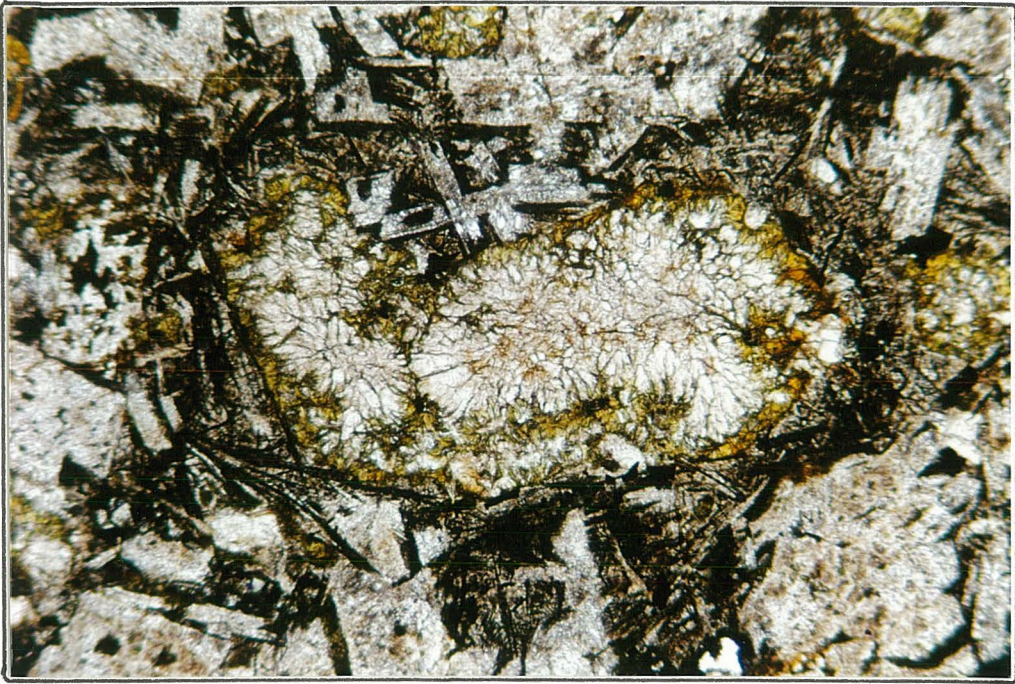


Figure 5.1c. Photomicrograph of the zeolite laumontite infilling an amygdale lined with a chlorite pseudomorph in a fine grained groundmass of acicular magnetite crystals (OU 63926). Magnification is x40.

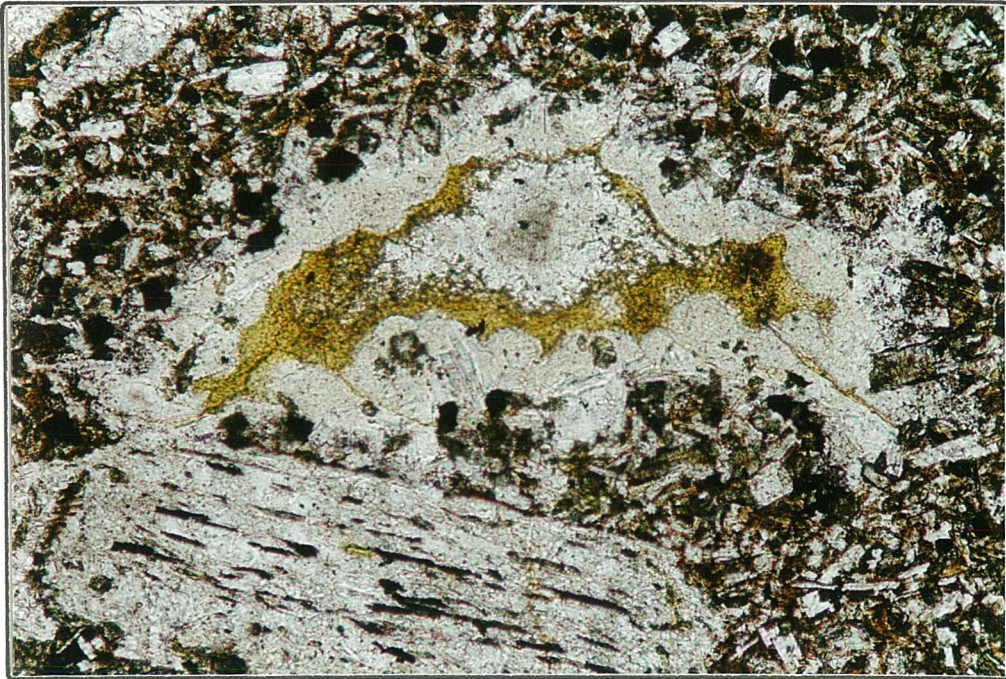


Figure 5.1 d. Photomicrograph of the zeolites thomsonite (in the middle) and rare gonnardite (botryoidal lining), infilling an amygdale. A chlorite-smectite occurs between the two (OU 63932). Magnification is x100.



Figure 5.1e. Photomicrograph show a good cleavage in the zeolite, heulandite which is infilling an amygdale within basaltic-andesites of the Heartbreak Formation (OU 63929). Magnification is x40.

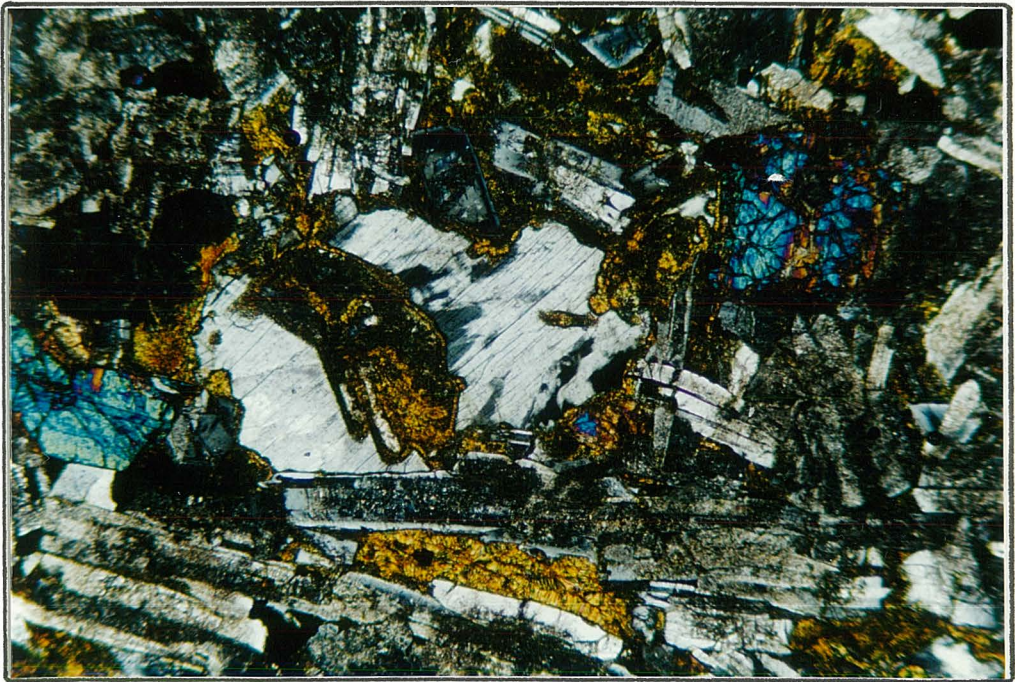


Figure 5.1f. Photomicrograph showing interpenetrating twins developed within the zeolite, stilbite. Note the good cleavage (OU 63973). Magnification is x40.



Figure 5.1g. Photomicrograph of calcite crystals (middle) and laumontite (rim) infilling a large vesicle in a 'red' rock (OU 63933). Magnification is x40.

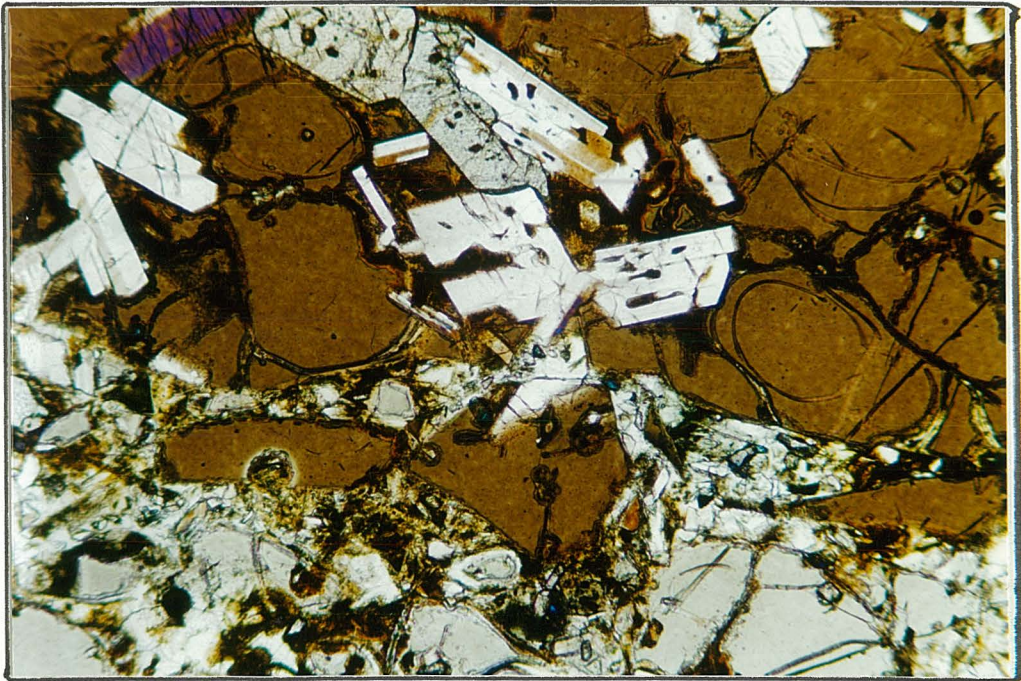


Figure 5.1h. Photomicrograph of the contact between two very well preserved glasses showing good botryoidal textures. Note the euhedral plagioclase and subhedral pyroxene crystals preserved within the brown glass at the top of the photo (OU 63934). Magnification is x40.

The majority of metamorphic minerals occurs within the actual rock and not just as veins and infilling fractures and amygdales. Minor macroscopic veining is present however, occurring in localised areas. Most vein systems are microscopic and they occur throughout all of the lithologies in the Takitimu Group.

The distribution of laumontite and its occurrence in veins and in the rock, for example, is restricted to areas where the Takitimu Group sequence is intruded concordantly by the White Hill Intrusive Suite. Some of the intrusions and associated sediments contain significant mineralised (zeolite) veins which may be an indication of localised hydrothermal mineralisation. The rest of the region shows gross overlaps with respect to the distribution of the different zeolite phases (Figure 5.2).

INTERPRETATION OF METAMORPHIC MINERALS

Laumontite is stable at higher temperatures than any of the other zeolites present in the area (Liou & Frey, 1991). The presence of this zeolite in areas where intrusive lithologies have been mapped may reflect higher temperatures induced by emplacement of the White Hill Intrusive Suite. It is also possible however, for laumontite to form under moderate to low temperatures (Figure 5.3).

The presence of thomsonite is significant in that it could only have formed in conditions of low silica activity, and under low to moderate temperatures (Coombs, et al. 1959).

Stilbite is a low temperature zeolite and hence might be expected to occur toward the top of the Takitimu Group sequence. Heulandite is the high pressure zeolite with respect to laumontite (Figure 5.3). Perhaps, under the circumstances present in the Nugget Hill region, we may expect laumontite to dominate in slightly older volcanic sequences of Heartbreak Spur and heulandite to occur in the younger MacLean Peaks lithologies. The pattern we find is not so neat. Heulandite and stilbite occur in both the MacLean Peaks and the Heartbreak Formations and are not restricted to certain horizons in the sequence.

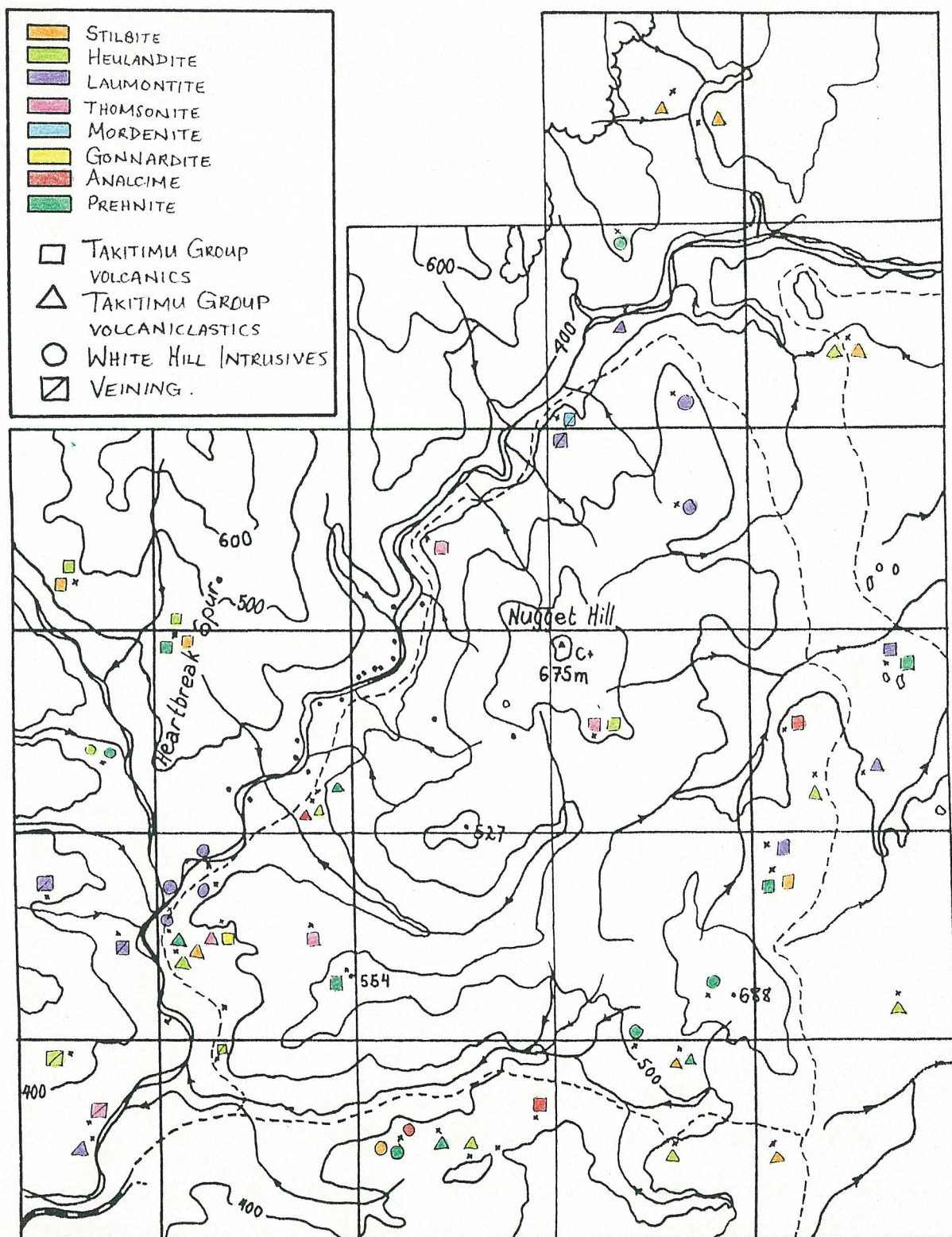


Figure 5.2. Map of the Nugget Hill area showing the distribution of the various metamorphic minerals including their lithological and depositional occurrences. Hydrothermal systems play a very minor role in the deposition of metamorphic minerals in this region. Burial metamorphism is thought to be the process of mineralisation.

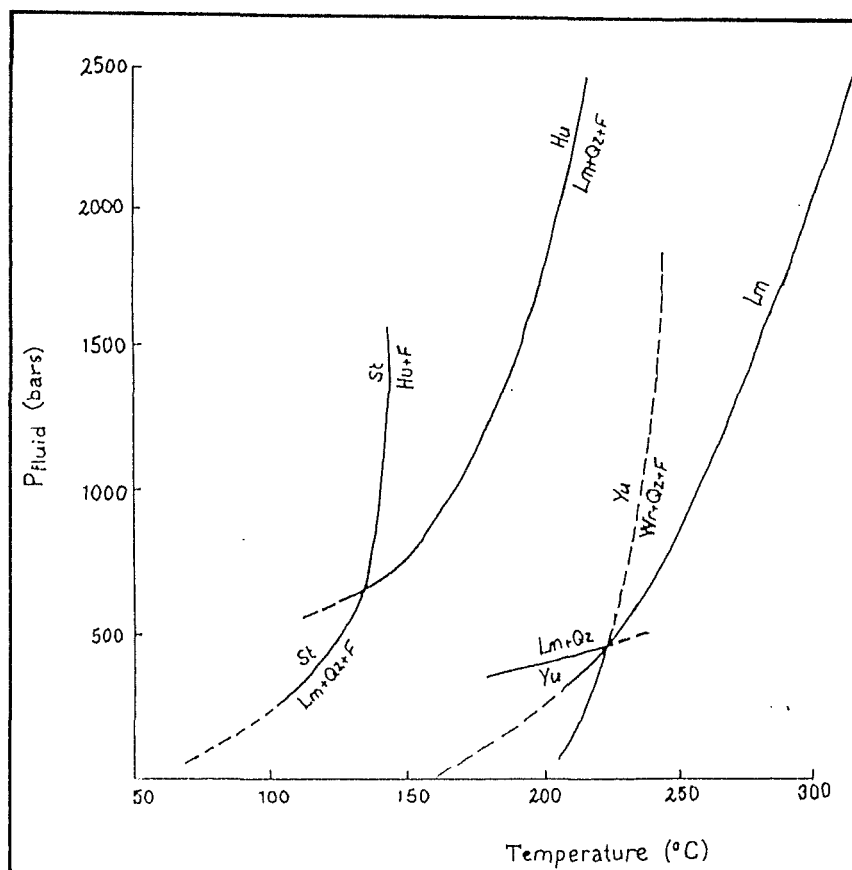


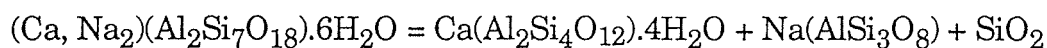
Figure 5.3. Experimentally determined P-T relations among various Ca zeolites, stilbite (St), heulandite (Hu), Laumontite (Lm), Yugawaralite (Yu) and Wairakite (Wr) in the presence of excess quartz (Qz) and fluid (F) (modified after Liou & Frey, 1991).

Zeolite assemblages observed today may not be the same assemblages present at the time of the initial metamorphic event. Changes in local conditions could induce dehydration reactions in ambient zeolite assemblages, slightly altering the minerals ^{to} producing the assemblages seen today.

Examples of possible Dehydration Reactions:

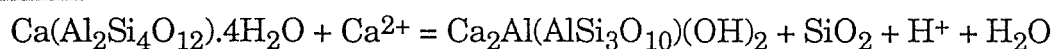
Under dehydration conditions it is possible for heulandite to react to form laumontite, albite, adularia, quartz and water (D.S. Coombs pers. comm. 1992).

Reaction:



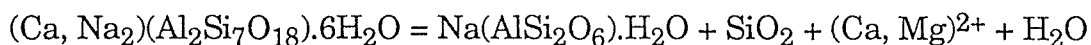
In veining, laumontite may react with calcium ions to produce prehnite, quartz and water (D.S. Coombs pers. comm. 1992).

Reaction:



Some of the volcanic samples from Heartbreak Spur don't have heulandite infilling vesicles, instead they contain analcime and quartz.

Reaction: (D.S. Coombs pers. comm. 1992).



These dehydration reactions help to understand some of the processes which may have occurred following metamorphism, soon after the Takitimu Group was formed.

DISCUSSION

Assuming the processes described are correct, they suggest that the conditions imposed on the Takitimu Group lithologies through burial of the sequence for prolonged periods gave rise to low temperature-moderate pressure and low temperature-low pressure metamorphic mineral assemblages (Figure 5.3).

After the initial phase of metamorphism, the climax of which probably occurred in the Late Permian (Houghton, 1986), soon after the formation of the Takitimu Group, intrusions, such as those of the White Hill Intrusive Suite, could have caused localised increases in the geothermal gradient within surrounding lithologies, and probably initiated some of the above dehydration reactions. The predominant formation of metamorphic minerals within the rocks rather than in veins suggests that the zeolites are mainly deuteritic in origin. The occasional occurrence of macroscopic veining indicates the presence of localised ancient hydrothermal systems. Systems which may have been set up by hot circulating fluids introduced in conjunction with the emplacement of the White Hill Intrusive Suite.

Chapter 6.

QUATERNARY TO RECENT GEOLOGY

Quaternary river terrace sequences are well preserved along both sides of the Telford Burn especially around the toe of Heartbreak Spur where there is an extensive flat area which is covered in large tussock and swampy ground (Figure 6.1). Extensive flat areas also occur to the east of the Wairaki River at the foot of the hills south of Nugget Hill. These are dominantly terrace deposits although one or two may be better described as broad alluvial fan deposits.

At least three episodes of terrace formation can be traced down either side of both the Telford Burn and at the south end of the Wairaki River. In the region of the Telford/Wairaki junction the oldest terrace is approximately 3-5 m above the present river level. In the Wairaki river just below Rock Hut there is a stratigraphic section through about 5 m of Quaternary river boulders, gravels and sands.

Holocene river gravels (no. 3. in Figure 6.1) are present in the bed of the Wairaki River and the braided bed of the Telford Burn. The second youngest terrace (no. 2. in Figure 6.1) is about 1 m above the present river level. This terrace (no. 2.) is only a few metres wide before the next oldest terrace steps up another metre and extends for about 10-15 m. The oldest terrace extends right to the foot of the hills (no. 1. in Figure 6.1). Redundant alluvial fans have developed at the foot of streams draining the hills to the west of the Telford Burn and the Wairaki River. There is very little in the way of recent slumping and landslides in the Nugget Hill area. Some areas which look like old slips are now completely covered in vegetation.

Sand samples were collected from the Wairaki River north of the Telford/Wairaki junction (G.R.142761), the Telford Burn (G.R.130747) and from the Wairaki River south of the Telford/Wairaki junction (G.R.131740). These samples were sieved and separated into groups on the basis of relative density using a wifly table. The predominating heavy minerals included magnetite, pyroxene, hornblende. Plagioclase, epidote, and quartz comprised the rest of the samples. There were no significant differences between the three samples and no gold or platinum was found in any of the samples.

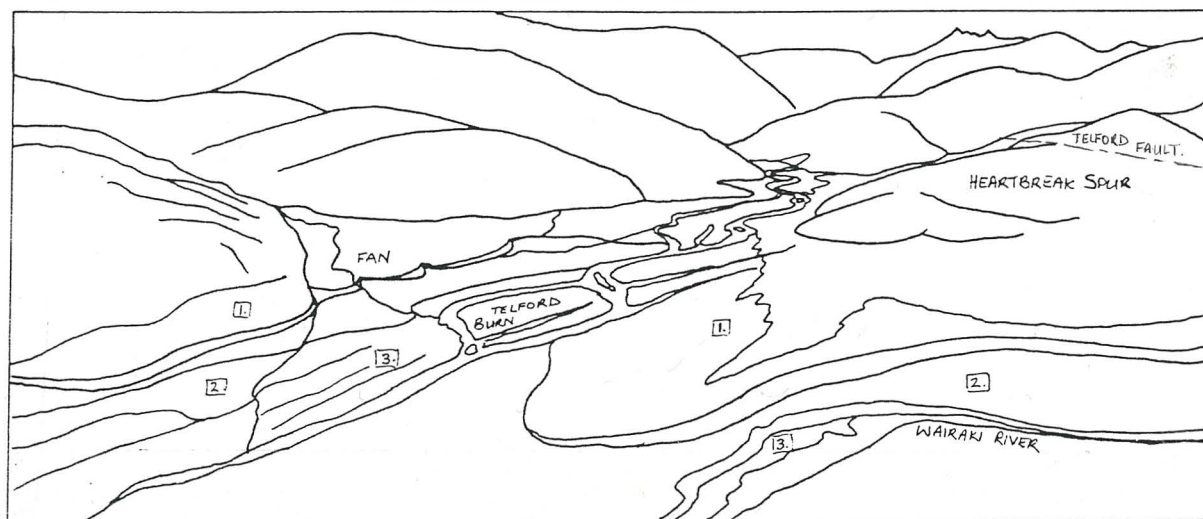


Figure 6.1. Photographic view looking up the Telford Burn toward the north, with the Wairaki River coming in from the right. Note the several generations of river terrace gravels and the faint fault trace across the toe of Heartbreak Spur (top right) (Photo taken from D44/134747).

Chapter 7.

STRUCTURAL GEOLOGY

INTRODUCTION

The Takitimu Group strata in the Takitimu Mountains form a 14 km thick subvertical homoclinal sequence of interbedded marine volcanoclastic sediments and basaltic to rhyodacitic volcanic rocks striking in a NW-SE direction (Houghton, 1981).

The Takitimu Group sequence in the Nugget Hill region however, changes from subvertical beds striking NW-SE and younging towards the east, northeast of Nugget Hill to more gently dipping beds, younging towards the south, southwest of Nugget Hill. This conspicuous change in strikes and younging directions defines a southeastward-plunging asymmetrical anticline (Nugget Hill Anticline) which has deformed the sequence in the region. The hinge^{plane attitude} of the anticline can be located quite well, as it follows the line of a stream which runs up and around the hill to the SW of Nugget Hill (Figure 7.1).

Houghton (1977) describes numerous faults striking parallel and subparallel to volcanoclastic beds and lensoid volcanic rocks of the Takitimu Group. Faults in the Nugget Hill area have been interpreted to occur mainly in the hinge region of the anticline, probably associated with 7 km of right lateral offset which occurred on the Telford Fault and with the folding event (Map).

FOLDING

Lithological layering of the Takitimu Group in the eastern and central regions of the mapped area strikes predominantly NNW and dips subvertically (75°W-75°E). These steeply dipping beds face east. South and southwest of Nugget Hill, the sediments strike E-NE and dip more shallowly (about 40°) towards the S-SE (Figure 7.2). Looking south from the north side of Phoenix Gully the EW strike ridges on the other side of the gully stand out quite well. These observations combined with data from Houghton's (1977) map and detailed studies of enlarged aerial photographs (Figure 7.4) suggests that the bedding orientations measured at D44/1395736, D44/134749 and D44/131746 may be representative of the general trend of these rocks on the southern limb of the fold. Younging directions within these lithologies indicate that the beds are not over turned and that the lithologies form the southern, gently dipping limb of the Nugget Hill Anticline.



Figure 7.1. Photograph and sketch looking east at the hinge region of the anticline, where strike orientations swing from an E-W orientation to the NNW-SSE (Photo taken from D44/7431395).

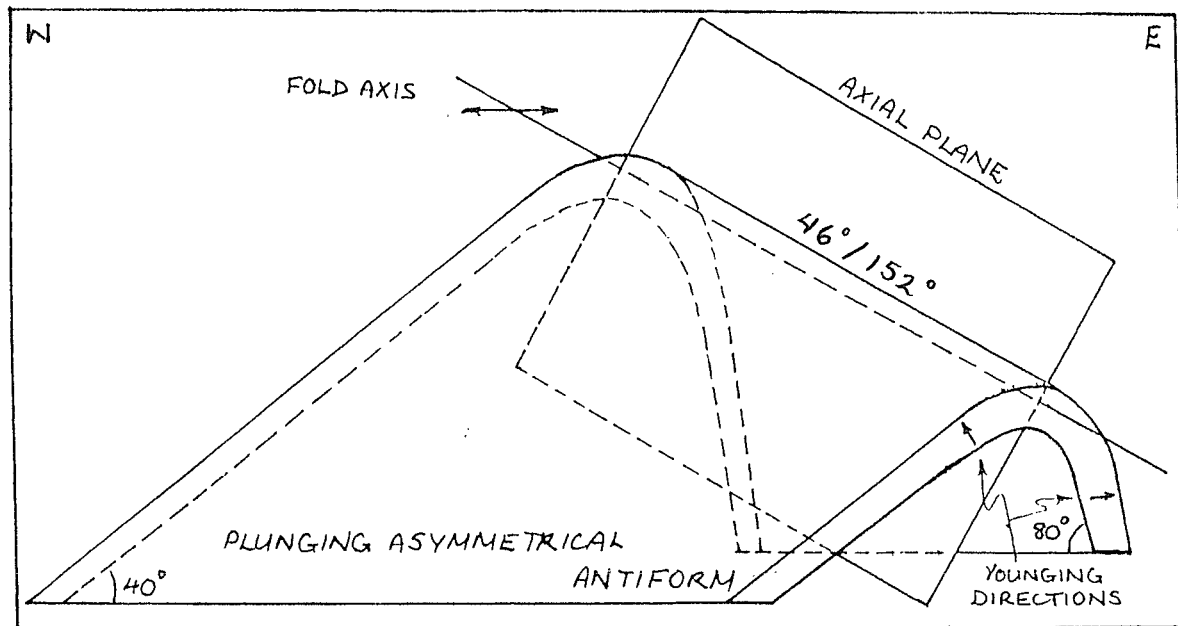


Figure 7.2. A diagrammatic sketch of the envisaged anticlinal structure in Takitimu Group rocks in the Nugget Hill area.

The aerial photographs of the southern Takitimu Mountains and the Nugget Hill area indicate a structural change from prominent NS strike ridges predominating to the northeast of the Nugget Hill region to roughly E-W strikes to the south of Nugget Hill and in the Telford Peak region (Figure 7.3).

Evidence for an isoclinally folded sequence in the southern Takitimu Mountains and in the Nugget Hill region at least, is supported by the data recorded in the Telford Peak region by Houghton (1977). He mapped six bedding orientations in this region and obtained strike directions between SW and WNW. Recorded dips range between 58°S and 35°S (Figure 7.4). Four out of the six measurements indicate younging directions towards the south, indicating that the beds to the north are not overturned. Similarly in the Nugget Hill region, bedding orientations measured south of Nugget Hill highlight shallower dips (32°S to 68°S), E-W strikes and younging directions toward the south (Figure 7.3).

The above observations lead me to conclude that northwest trending beds in the northwest limb of the Nugget Hill Anticline may be repeated in the south limb. But as the lithologies in the Telford Peak region are not mapped by Houghton (1977), it is not known whether these are the same part of the sequence or not. Houghton (1977) inferred the presence of faults, one running EW to the north of Telford Peak and another trace down the Telford Burn to explain the abrupt changes in bedding orientations but he did not differentiate Takitimu Group lithologies in this area.

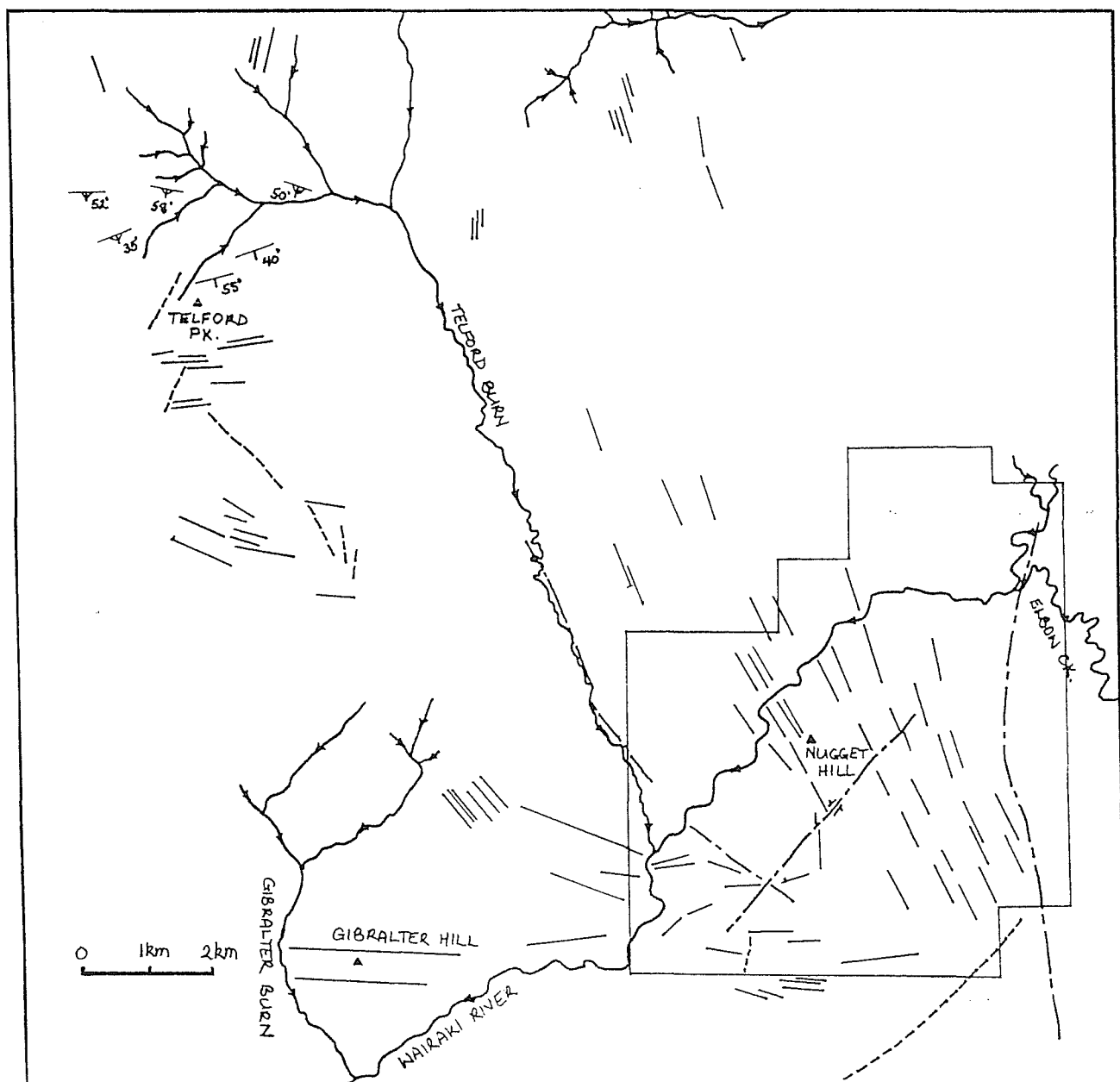


Figure 7.3. Structural landmarks, such as strike ridges, obtained from an aerial photograph of the southern Takitimu Mountains and the Nugget Hill area. The Telford Burn follows an inferred fault which offsets east-west strikes, south of Nugget Hill from similar trends north of Telford Peak. Six bedding orientations obtained from Houghton's (1977) map are also plotted.

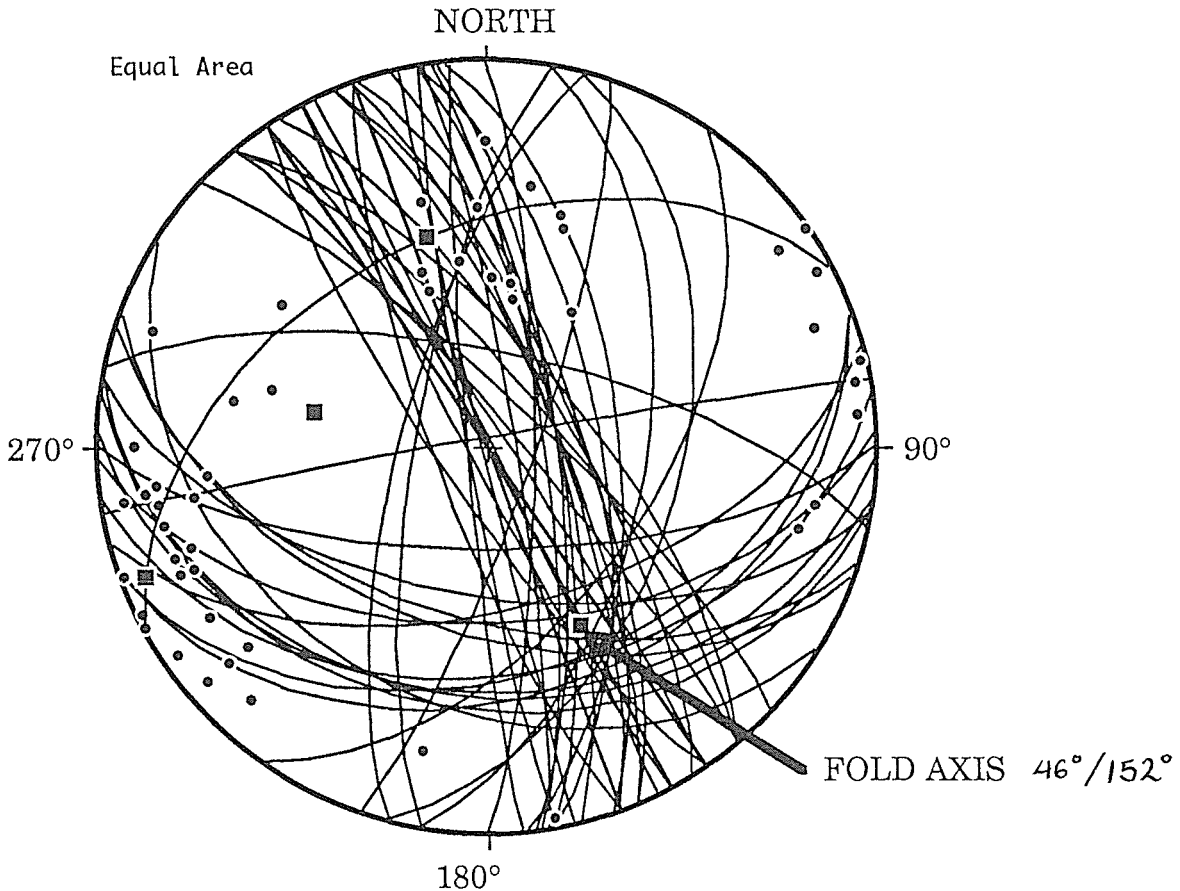


Figure 7.4. An equal area stereo plot of bedding orientations taken in the Nugget Hill area combined with the orientations taken on the west at the head of the Telford Burn by Houghton (1977).

FAULTING

There is very little field evidence for faulting in the Nugget Hill region. The aerial photographs however show several clearly defined lineaments rather well. The conspicuously straight trace of the Telford Burn and a possible region of minor uplift along the bottom right-side of the river is interpreted as a large, dominantly strike-slip fault (Telford Fault) striking approximately northwest, sub-parallel to strikes of the Takitimu Group to the northeast. The Telford Fault is inferred to offset the southern limb of the Nugget Hill Anticline in a right lateral ^{separation of} ~~sense by about~~ 6 or 7 km, assuming beds in the Telford Peak region correlate with those of Phoenix Gully (Figure 7.3).

The Telford Fault is thought to splay at its southern end into three faults. An extension of the right lateral movement bends slightly towards the southeast at the toe of Heartbreak Spur, across the Wairaki River and up a major creek, south of Nugget Hill (see Map). Another splay of the Telford fault is inferred to run down the Wairaki River south of Heartbreak Spur. These inferences are based on intense fracturing and alteration of the lithologies observed on either side of the Wairaki River in this region. These faults have ^{? left lateral possibly conjugate to Telford Fau}

isolated the block of roughly-stratified lithologies to the east of the Wairaki River, south of Heartbreak Spur. The three splays at the southern end of the Telford fault disperse the 7 km of offset along the main fault into small amounts of movement on each of the subsidiary faults.

Several small (150 m) lithological offsets have been mapped to the southeast of Nugget Hill along a 2 km, thrust fault (Nugget Hill Thrust), which strikes northeast and dips southeast. Uplift on the southeast side of the Nugget Hill thrust gives rise to the apparent left lateral ^{displacement.} offset at the surface. This thrust may also have accommodated some of the movement at the south end of the Telford fault.

Two small shear zones are located at D44/127737 and D44/170778 and of these two, the sense of movement could be established on the shear zone of the northwest, in the south bank of the Wairaki River (Figure 7.5). It is the best exposure of the two, is filled with a reddish-brown fault gouge about 8 cm wide and has a sheared fabric indicating a reverse slip component. This discontinuity may be associated with the Letham Ridge Thrust which separates Triassic rocks of the Murihiku Supergroup from underlying Jurassic Barretts Formation.



Figure 7.5. Photograph of a small shear zone (oriented 064°/80°SE) within siltstone of the Murihiku Supergroup (D44/170778). The hammer is 57 cm long.

The Tin Hut Fault was not observed in this study and was mapped using data from Aslund's (1988) map.

Although no faults parallel to bedding in the Takitimu Group rocks were mapped, I have no doubt that they are there because there are numerous localities where slickenside lineations are well-exposed on bedding planes.

Chapter 8.

DISCUSSIONS & CONCLUSIONS

SUMMARY

In the Nugget Hill region volcanoclastic lithologies such as rudite, arenite and lutite (MacLeans Formation) dominate over the igneous lithologies, basalts and basaltic-andesites (Heartbreak Formation) within the Takitimu Group. Their field relations, similar lithologies, petrography and geochemistry leads to the conclusion that both the Heartbreak Formation and the MacLeans Formation were deposited in the same island arc system. The Heartbreak Formation lithologies are dominated by primary volcanic flows which represent a near-vent facies. ^{Rocks} ~~Lithologies~~ of the MacLeans Formation were deposited in sedimentary basins flanking the arc and developed contemporaneously with the arc volcanism.

Petrology, geochemistry and field distributions indicate that the White Hill Intrusive Suite has very close associations with the lithologies of the Takitimu Group. The gabbros and microgabbros are thought to be derivatives of the same magmas from which the Takitimu Group volcanics were derived. Magmas of the White Hill Intrusive Suite were intruded into the volcanic-volcanogenic sequence penecontemporaneously with the duration of the island arc system. During the intrusive activity, bedding and flow planes formed principal planes of weakness within the volcanic pile and hence concordant sill-like intrusions predominated. Narrow discontinuous cross-cutting dykes were also intruded into the sequence. This subvolcanic plutonism contributed to the overall growth of the volcanogenic pile.

The Barretts Formation is a sequence of Jurassic conglomerates, sandstones and silts, composed dominantly of granitic and silicic volcanic material, overlying the Takitimu Group along an erosional angular unconformity. Barretts ^{sediments} ~~lithologies~~ were deposited in a marginally marine fluvial environment proximal to Jurassic plutons of granitic composition, near to the continental margin of Gondwana. It has in the past been assumed that the granitic source has since been removed. However plutonic rocks of appropriate age and composition intrude the Plato "terrane", part of the Brook Street Supergroup, and could conceivably represent a source for the granitoid detritus in the Barretts Formation (Powell 1992). Petrographical studies also indicate that much of the Barretts may have been derived from Triassic sediments of the Murihiku Supergroup, a sequence of volcanoclastic sediments derived from a continental arc margin. If the Barretts was indeed derived from

Triassic Murihiku Supergroup rocks, one might expect to see erosional surfaces within the Murihiku sequence.

TIMING OF FOLDING & TILTING

As yet, there have been little suggestion as to the timing of structural events which led to the tilting and folding of the Takitimu Group sequence.

The time of the tilting of the Takitimu Group sequence in the Nugget Hill region is constrained to have occurred in pre-Jurassic time because of the angular unconformity which exists between the Middle Permian Takitimu Group and Jurassic lithologies of the Barretts Formation. The Late Permian of the Productus Creek Group to the east, can be used to ^{constrain} further ~~constrain~~ the timing of tilting, and hence folding, because of its relative concordance with the Takitimu Group. There is no trace of the Triassic which must once have occurred between the Takitimu Group and the Barretts Formation. Hence it must have been a period of uplift and erosion. The timing of the anticline in the region is more difficult to determine because no contacts with sediments of a younger age were observed in the folded region. I suspect the folding was coincident with the uplift event, as beds on the southern limb of the anticline are dipping at slightly shallower angles to those of the northeast.

NEW ZEALAND CORRELATIONS

Rocks of the Brook Street Terrane have been recognised throughout the South Island of New Zealand. However, it is not possible to correlate all Brook Street occurrences on the basis of lithological similarities.

The Takitimu Group of the Nugget Hill region in the southern Takitimu Mountains can be correlated with Brook Street Occurrences in the north of the South Island on the basis of age and lithological similarities.

The Brook Street Group in Nelson comprises three formations which all ~~comprise~~ ^{consist of} steeply dipping, southeast facing sequences (Johnston, 1980, 1990). The basal Grampian Formation comprises fine-grained sediments containing scattered beds of Atomodesmatinid limestone, lenses of tuff and flows of grey spilite. This formation is overlain by the Kaka Formation which is characterised by augite-rich basaltic pyroclastics along with occasional basaltic flows. The Groom Creek Formation is the uppermost unit comprising andesitic tuff and sandstone.

Takitimu Group rocks are most similar to the Kaka Formation, with the abundance of augite-rich, plagioclase phyric basalt-basaltic andesite volcanics and volcanoclastics.

D'Urville Island is closely associated with the Takitimu Group in that it also comprises very similar rocks to those of the Kaka Formation. Volcanoclastics in which clinopyroxene-rich breccias and tuffs with lesser basaltic turbidite are well developed on the island. Ankaramitic occurrences in the upper Takitimu Group in the Nugget Hill region argue more strongly for the correlation with D'Urville Island because ankaramites have been long known to occur on the island.

Augite-rich basalt-andesitic volcanics and volcanoclastics of the Kaka Formation are again well developed in the Lake Rotoiti region.

The Takitimu Group of the Nugget Hill region is characterised by basalt to basaltic-andesite calc-alkaline volcanism. It appears to lack primitive tholeiitic magmas. The bulk of the Brook Street terrane however, comprises primitive basaltic magmas which were generated during the early phase of oceanic arc volcanism. It would seem that the Brook Street represents an oceanic arc system which was dominated by primitive tholeiitic volcanism and was contemporaneously interspersed regions of more evolved magma compositions.

CORRELATIONS WITH GYMPIE & NEW CALEDONIA

Correlations between the Takitimu Group in New Zealand, the Gympie Group, Australia and New Caledonia are based primarily on very similar lithologies and ages.

SIMILARITIES

Common lithologies in the Gympie and Takitimu Groups include pyroclastic rocks comprising mainly marine basaltic compositions intercalated with subordinate lava flows and dykes. Amygdaloidal basaltic agglomerates, ash-fall tuffs, and minor flows, as well as volcanoclastic arenites, turbidites and volcanogenic rudites are very distinctive in the Gympie Group and the MacLean Peaks Formation.

Augite porphyries and hematitic staining, both of which have been described from the MacLean Peaks Formation, have been observed within the Gympie Group (Waterhouse & Sivell, 1987). The Gympie Group is also similar

to the Takitimu Group in the Nugget Hill region, in that it contains rare occurrences of richly chrome-diopside phyric ankaramites.

Similarly New Caledonia comprises fine tuffs, augite porphyries and basalt to basaltic-andesite submarine flows. Some dacite and rhyolitic tuffs have also been reported (Paris & Lillie 1977 in Waterhouse & Sivell 1987).

Early-Middle Permian ages have been established for the Takitimu Group in the Nugget Hill region. Late Permian ages have been determined for the Gympie Group and New Caledonia. Campbell et al. (1985) correlated the Late Permian pyroclastic beds, massive lava and interbedded pyroclastic flows in the Gympie Group with the *Trabeculatia trabecula* zone in New Zealand on the bases of their similar faunas.

DISSIMILARITIES

Sequence thicknesses in the Gympie Group (3 km) and in New Caledonia (1.12 km) are not comparable to the 14 km thick sequence present in the Takitimu Group of Southland, New Zealand, even if parts of the Takitimu sequence in the Takitimu Mountains are repeated.

The absence of andesite lavas and ultramafic-gabbroic sill complexes within the Gympie Group is a dissimilar feature of the Gympie group in comparison with the Takitimu Group of the central Takitimu Mountains (Houghton 1977). The Takitimu Group of the Nugget Hill region contains no andesitic lavas but it does have gabbroic and microgabbroic intrusions. Campbell et al. (1985) indicated that Gympie Group volcanics are generally more acidic than volcanics of the Takitimu Group.

The absence of a mid-ocean ridge sequence, such as the Dun Mountain ultramafic belt and the Patuki Volcanic Complex (Waterhouse 1964 in Waterhouse & Sivell 1987), in the Gympie Group and New Caledonia is another dissimilarity. Waterhouse & Sivell (1987) suggest that a spreading ridge system was active near New Zealand but dies out towards Gympie and New Caledonia. Hence New Zealand received substantial thicknesses of marine sediment while Gympie lay towards the end of the mid-ocean ridge, and New Caledonia must have been close to the terminus of the volcanic arc and received more terrestrial sediment.

Chapter 9.

GEOLOGICAL SCENARIO

The following geological scenario is based, collectively, on research into representative geological environments for each of the formations discussed. Elaborating on work previously done by Houghton (1977) in the central Takitimu Mountains, Aslund (1988) to the east and Willsman (1990) to the south, I intend to describe a scenario for the course of events leading to the geology observed in the Nugget Hill region today.

Houghton (1977) proposes an Island Arc model, which changes composition from basaltic to rhyodacitic then back to basaltic through to basaltic-andesite again, for the rocks of the Takitimu Group in the central Takitimu Mountains. Nugget Hill rocks are of basaltic to basaltic-andesite composition and hence represent the initial stages of an island arc system.

The sequences observed in the region suggest an origin for both volcanic and volcanoclastic lithologies involving, initially, a basaltic Island Arc setting where a subduction system gave rise to the formation of magma chambers above the subducting slab. Initially magmas within the magma chamber had basaltic compositions which migrated up through oceanic crust forming a chain of volcanoes. Over several millions of years the volcanoes produced lava flows, pillow lavas and volcanogenic sediments. The lava flows over-rode one another forming regional highs and lows. Erosion continuously produced volcanoclastic material, derived from the volcanoes and their lava flows, which was transported down and along valleys, into marine channels, and down great canyons into large channeled fan systems and eventually into the basin plain at the foot of the arc system (Figure 9.1a).

The coarser rudites were probably deposited in feeder channels coming directly from the arc volcanoes and in parts of the upper fan. As the feeder channel branched off into channeled fans, coarse sands were rapidly deposited, forming massive thick beds overlain by thinner mud layers. Turbidite beds were deposited laterally between the massive coarse sands in the upper fan and the very fine muds in the basin plain.

As subduction proceeded, tectonic plate motions in conjunction with sediment accretion initiated the migration of the volcanic island arc system away from the plate margin. Contemporaneous magma differentiation processes gave rise to more andesitic volcanoes in-place of the basaltic

volcanoes. These originally basaltic volcanoes would either have host vents for basaltic-andesite magmas or may have become inactive and eventually partially or completely eroded by alluvial and marine processes (Figure 9.1b).

Penecontemporaneous with the formation of the Takitimu Group lithologies, magmas of the White Hill Intrusive Suite were intruded along and across contacts of the volcanic and volcanoclastic sequences directly from underlying magma chambers. Similar compositions of the White Hill Intrusives and extruded Takitimu Group lavas can be explained in terms of a common magma chamber from which both magmas were derived. The difference being that the White Hill Intrusive magmas were not extruded at the surface, as were the Takitimu Group volcanics; hence they crystallised over longer periods of time forming coarser and more abundant phenocrysts.

With cessation of volcanism and the continuation of erosion processes, came perhaps, degradation and burial of the arc system under a pile of sediments initially derived from the arc itself then later by oceanic sediments (Figure 9.1c). Thermal subsidence and prolonged burial under high pressure, low temperature gradients lead to the development of the zeolite facies. Localised "hot spots" where intrusions of the White Hill Intrusive Suite occurred gave rise to a slightly higher temperature zeolite, laumontite in the intrusions themselves and in surrounding lithologies. Incipient alteration resulted from the presence of abundant volcanic glass, sea water derived fluids, and rapid burial (common in arc volcanoes). It is worth noting that the Barretts Formation also contains zeolite mineral facies assemblages hence metamorphism of the Brook Street Supergroup rocks could have also occurred much later than the last phase of magmatic arc activity.

By Jurassic times the rocks of the Takitimu Group in the Nugget Hill area had undergone uplift, tilting and structural deformation. This was probably caused by the collision with a continental land mass (Gondwana) (Aslund, 1988) (Figure 9.1d). The large southeastward plunging asymmetrical anticline in the Nugget Hill area is very significant in terms of the structural history of southern Takitimu Group lithologies. Although the Nugget Hill region is considerably smaller than the whole of the Takitimu Mountains, I think that the structure of Takitimu Group rocks in the southern Takitimu Mountains at least, may be more complex than previously thought. This has important implications for Houghton's (1977) interpretations of the stratigraphic relations of the Takitimu Group. The Takitimu Group may not represent a continuous volcanogenic sequence of 14 kilometres' thickness. The

anticline in the Nugget Hill area suggests that the sequence is more complex here and that there may be repetition occurring in other parts of the Takitimu Group sequence. Lithological similarities within the Group make it very difficult to tell whether the sequence in other areas is being repeated or not.

Conglomerates and sandstones of the Barretts Formation *were* deposited during Mid Jurassic times either in a fluvial setting with marine influence or perhaps in a bouldery beach setting. These lithologies were derived partially from Takitimu Group rocks but predominantly from granitic bodies and siliceous volcanics which were somewhere in the vicinity during the Jurassic period. At some stage after the Jurassic the Triassic Murihiku Supergroup was thrust over the Barretts Formation and the Takitimu Group along the Letham Ridge Thrust (Figure 9.1e). Offset of the Letham Ridge Thrust across the Tin Hut Fault between the area mapped by Aslund to the east and the Nugget Hill region indicates that the Tin Hut Fault is a later structure which faults the Takitimu Group, the Barretts Formation and the Murihiku Supergroup.

There are still many unknowns in relation to the geological reconstruction of the relevant geological units including the unknown degree of deformation within the Takitimu Group sequence, timing of the metamorphism of the Takitimu Group, the Barretts Formation and the Murihiku Supergroup. The relative positions of the Brook Street and Murihiku Supergroups at the time of Murihiku and Barretts deposition needs to be better established in order to interpret the sources for both the Murihiku Supergroup and the Barretts Formation. Although Barretts paleocurrent directions obtained in this study indicate a NW-SE direction, a lot more information is required to give evidence for the position of the source.

GEOLOGICAL SCENARIO

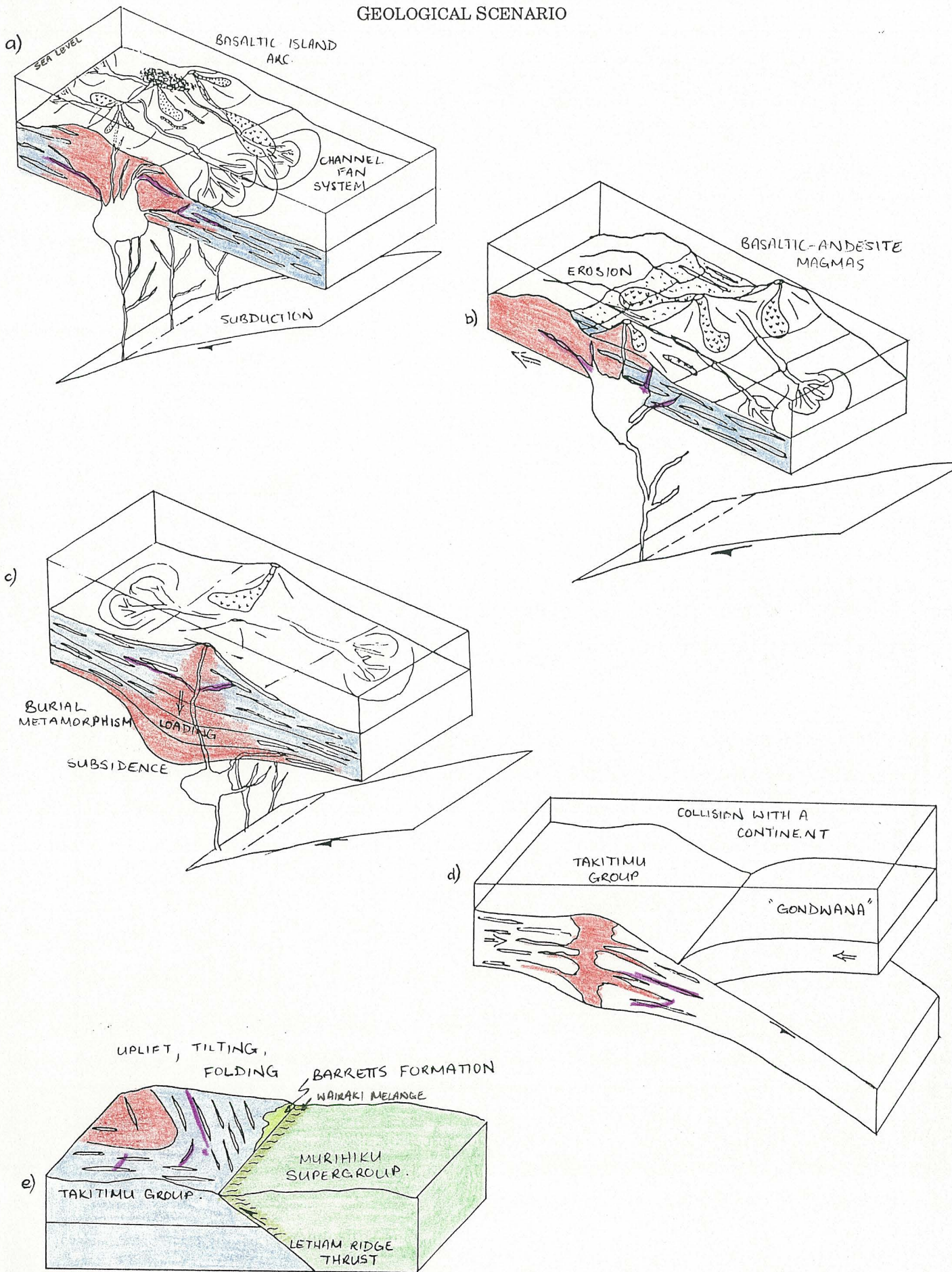


Figure 9.1a-e. Reconstruction of a possible geological scenario for the rocks in the Nugget Hill region.

REFERENCES CITED

- Aslund, T., 1988. Permian-Jurassic Relations, Beaumont Area, Western Southland. *BSc Honours Thesis (unpublished)*.
- Aslund, T., 1989. The Brook Street and Murihiku Terranes- Evidence for the timing of juxtaposition. *Geological Society of NZ. Abstract from New Zealand Geology and Geophysics Conference* vol. 43, p.22.
- Avias, J. 1953. Contributions a l'Etude Stratigraphique et Pale'ontologique des Formations antedre'tace'es de la Nouvelle-Caledonie Centrale. *Sci. Terre*. 1. p. 1-276.
- Ballard, H. R., 1989. Permian Arc Volcanism and aspects of the General Geology of the Skippers Range, NW Otago. *Doctor of Philosophy (Unpublished)*.
- Basaltic Volcanism Study Project. 1981. Basaltic Volcanism on the terrestrial planets. *New York, Pergamon Press*.
- Blattner, P. & Williams, J. G., 1991. The Largs high-latitude oxygen isotope anomaly (New Zealand) and climatic controls of oxygen isotopes in magma. *Earth and Planetary Science Letters*. vol. 103., p. 270-284.
- Bowen, F. E., 1964. Geology of the Ohai Coal Field. *New Zealand Geological Survey Bulletin*. vol. 51.
- Brown, E. H., 1966. The Greenschist Facies in Part of Eastern Otago, New Zealand. *Contrib. Mineral. and Petrol*. vol. 14, pp. 259-292.
- Cas, R. A. F. & Wright, J. V., 1987. Volcanic Successions: Modern and Ancient. *Allen & Unwin (Publishers) Ltd*.
- Campbell, H. J. Grant-MacKie, J. A. & Paris, J. P., 1985 Geology of the Moindou-teremba area, New Caledonia. Stratigraphy and structure of Teremba Group (Permian-Lower Triassic) and Baie de St-Vincent Group (Upper Triassic-Lower Jurassic) *Ge'ol. Fr*. 1. p.19-36.
- Cox, S. H., 1878. Report on the Geology of the Hokonui Range, Southland. *New Zealand Geol. Survey Rep. Geol. Explor. 1877-1878*. vol. 11, p. 25-48.
- Devereaux, I., McDougall, I. & Walters, W. A., 1968. Potassium-Argon mineral dates on intrusive rocks from the Foveaux Strait area. *New Zealand Journal of Geology and Geophysics*. vol.11, p. 1230-1235.
- Fisher, R. V. & Schmincke, H.-U., 1984. Pyroclastic Rocks. *Springer-Verlag Berlin Heidelberg New York Tokyo*.
- Frey, R. W. & Pemberton, S. G., 1984. Trace Fossil Facies Models. *Facies Models*. edited by Walker, R. G. p. 189-207.
- Frost, C. D. & Coombs, D. S., 1989. Nd Isotope character of New Zealand sediments: Implications for terrane concepts and crustal evolution. *American Journal of Science*. vol. 289, p. 744-770.
- Gill, J. B., 1981. Orogenic Andesites and Plate Tectonics. *Springer-Verlag Berlin Heidelberg New York*.

REFERENCES CITED

- Grindley, G.W., 1958. The Geology of the Eglinton Valley, Southland. *Bull. NZ Geol. Surv. n.s.* 58.
- Guerange, B., Lillie, R. & Jozes, J. 1975. Etude geo'logique des terrains ante-Oligoce'nes de la chaine centrale Neocaledonienne: stratigraphique regimes de sedimentation evolution structural et metamorphique. *Bull. Bur. Rech. Geol. Min.* 2nd Ser., Sect. 4 (2) p. 121-137.
- Harrington, H. J., 1983. Correlation of the Permian and Triassic Gympie terrane of Queensland with the Brook Street and Maitai terranes of New Zealand. In: Permian Geology of Queensland. *Geological Society of Australia Queensland Division, Brisbane.* pp.431-436.
- Haston, R.B., Luyendyk, B.P., Landis, C.A., and Coombs, D.S., 1989: Paleomagnetism and question of original location of the Permian Brook Street terrane, New Zealand. *Tectonics* 8: 791-801.
- Houghton, B. F., 1977. Geology of the Takitimu Group and associated intrusive rocks, central Takitimu Mountains, western Southland, New Zealand. Unpublished Ph. D. Thesis, lodged in the library, University of Otago, Dunedin, New Zealand.
- Houghton, B. F., 1981. Lithostratigraphy of the Takitimu Group, central Takitimu Mountains, western Southland, New Zealand. *New Zealand Journal of Geology and Geophysics.* vol. 24, pp. 333-348.
- Houghton, B. F., 1985. Petrology of the Calc-Alkaline lavas of the Permian Takitimu Group, Southland, New Zealand. *New Zealand Journal of Geology and Geophysics.* vol. 28, pp. 649-665.
- Houghton, B. F., 1986. The Calc-Alkaline White Hill Intrusive suite, Central Takitimu Mountains, western Southland, New Zealand. *New Zealand Journal of Geology and Geophysics.* vol. 29, pp. 153-164.
- Houghton, B. F. & Landis, C. A., 1989. Sedimentation and Volcanism in a Permian arc-related basin, southern New Zealand. *Bulletin of Volcanology.* vol. 51, pp.433-450.
- Hutton, F.W., 1872. Reports on the Geology of Southland. *New Zealand Geological Survey Report Geol. Exploration 1871-1872.* vol.7, p. 89-112.
- Hutton, F. W. & Ulrich, G. H. F. 1875. "Geology of Otago". *Mills, Dick, Dunedin.* 244 pp.
- Johnston, M. R., 1980. Sheet 027 AC-Dun Mountain (1st ed.) Geological Map of New Zealand, 1:50000, Wellington, Department of Science and Industrial Research.
- Johnston, M. R., 1990. Geology of the St Arnand District, Southeast Nelson (Sheet N29). *New Zealand Geological Survey Bulletin.* vol. 99, p. 18-21.
- Landis, C.A., and Coombs, D.S., 1967: Metamorphic belts and orogenesis in southern New Zealand. *Tectonophysics* 4: 501-518.
- Landis, C. A., Cawood, P.A., Kimbrough, D. L. & Pillai, D. D. L., 1987. Letham Ridge Fault, a newly recognised terrane boundary in western Southland. *Geological Society of New Zealand Miscellaneous Publication* 37A.
- Landis, C. A., 1987. Permian-Jurassic rocks at Productus Creek-Letham Ridge, Southland. Tour guide to Post Conference Field Excursion B4. *Geological Society of New Zealand Annual Conference, Dunedin, 1987.*
- Lindsay, N. M., 1980. The Geology of the Dunton Range, Te Anau. *BSc Honours Thesis*

(Unpublished).

- Liou, J. G. & Frey, M. 1991. Zeolite equilibria in the system $\text{CaAl}_2\text{Si}_3\text{O}_8$ - $\text{NaAlSi}_3\text{O}_8$ - SiO_2 - H_2O .
New Zealand Journal of Geology and Geophysics. vol. 34, p. 293-301.
- Moore, J. G. & Schilling, J. G. 1973. Vesicles, water and sulphur in Reykjanes Ridge basalts.
Contrib. Mineral. Petrol. vol. 41, p. 105-118.
- Mutch, A. R., 1957 Facies and thickness of upper Paleozoic and Triassic sediments of Southland.
Transactions of the Royal Society of New Zealand. vol. 84, pp. 499-511.
- Mutch, A. R., 1972. Geology of the Morley Subdivision. *New Zealand Geological Survey Bulletin* . vol 76.
- Paris, J. P. & Lillie, R. 1977. New Caledonia: evolution from Permian to Miocene. Mapping data and hypotheses about geotectonics. *Int. Symp. Geodynam. Southwest Pacific, Noumea (New Caledonia)* 1976, p. 195-208.
- Paris, J. P. & Bradshaw, J. D., 1977. Paleogeography and Geotectonics of New Caledonia and New Zealand in the Triassic and Jurassic. *International Symposium on Geodynamics in South-West Pacific Noumea (New Caledonia)*. pp.209-216.
- Park, J., 1910. "The Geology of New Zealand". *Whitcombe & Tombs Ltd, Christchurch*. xx + 487 pp., 27 pl., 143 fig.
- Park, J., 1921. Geology and Mineral Resources of western Southland: *New Zealand Geological Survey. Bulletin* 23.
- Powell, N. G., 1992. High Pressures attending Granulite Facies Metamorphism in Fiordland may have been induced by "Obduction" of the "Murihiku Arc". *Geological Society of New Zealand Miscellaneous Publication, Christchurch Conference Abstracts with Programme*.
- Rout, M. V. & Willet, R. W., 1949. The Geology of the Wairaki Survey District. *Trans. Roy. Soc. New Zealand*. vol. 77, No. 2, p. 291-305.
- Shelley, D. 1975. Optical Mineralogy. (2nd ed.) *Elsevier. New York, Amsterdam, Oxford*.
- Sivell, W.J. & Rankin, P.C., 1983. Arc-tholeiite and ultramafic cumulate, Brook Street Volcanics, west D'Urville Island, New Zealand. *NZ J. Geol. Geophys.* 26, p. 239-257.
- Speden, I. G. & Keyes, I. W., 1981. Illustrations of New Zealand Fossils. A New Zealand Geological Survey Handbook. *New Zealand Dept. of Scientific Research*. No. 150, p. 22-25.
- Staudigel, H. & Schmincke, H. U. 1984. The Pliocene seamount series of La Palma/Canaria Islands. *Journal of Geophysical Research*. vol. 89, p. 11195-11215.
- Teichert, C. (Editor), 1981. Treatise on Invertebrate Paleontology: F (Supplement 1. Rugosa, Tabulata) *Geological Society of America, Inc.* p.F635-F636.
- Thomson, J. T., 1859. Reports on the reconnaissance survey of the Southern Districts of Otago. *Otago Prov. Gov. Gaz.* vol. 3, p.256-266.
- Turnbull, I. M., 1986. Geological Map of New Zealand. 1:50000 Sheet D42 BD & Part Sheet D43, Snowdon. *New Zealand Geological Survey, Dunedin. D.S.I.R.*

REFERENCES CITED

- Van der Plas, L. & Tobi, A. C., 1965. A chart for determining the reliability of point counting results. *American Journal of Science* vol. 263, p. 87-90.
- Walker, R. G., 1975a. Generalised facies models for resedimented conglomerates of turbidite associations. *Geological Society of America, Bulletin.* vol. 86 p. 737-748.
- Walker, R. G., 1978. Deep water sandstone facies and ancient submarine fans: models of exploration for stratigraphic traps. *American Association of Petroleum Geologists Bulletin.* vol. 62., p. 932-966.
- Walker, R. G., 1984. Facies Models, Second Edition. *Geological Association of Canada.* Turbidites and Associated Coarse Clastic Deposits. p. 171-188.
- Waterhouse, J. B., 1956. Recent French contributions to the geology of New Caledonia. *NZ J. Sci. Technol.* 37B, p.587-596.
- Waterhouse, J. B., 1958. The Age of the Takitimu Group in Western Southland. *New Zealand Journal of Geology and Geophysics.* vol. 1. p. 604-610.
- Waterhouse, J. B., 1964. Permian Stratigraphy and Faunas of New Zealand. *New Zealand Geological Survey Bulletin* . No.72.
- Waterhouse, J. B., 1967. Proposal of series and stages for the Permian in New Zealand. *New Zealand Geological Survey Bulletin* . No.72.
- Waterhouse, J. B., 1970. A new Permian fauna from New Caledonia and its relationships to Gondwana and Tethys. *I.U.G.S. Symp. on Gondwana Stratigraphy, Buenos Aires, 1967.* p. 249-272.
- Waterhouse, J. B., 1980. New Zealand Permian Brachiopod Systematics, Zonation, and Paleocology. *New Zealand Geological Survey Paleontological Bulletin.* No. 48.
- Waterhouse, J. B. & Sivell, W. J. 1987. Permian evidence for Trans-Tasman relationships between East Australia, New Caladonia and New Zealand.
- Williams, J. G., 1978. Eglinton Volcanics-stratigraphy, petrography, and metamorphism. *New Zealand Journal of Geology and Geophysics.* vol. 21, No. 6, pp. 713-732.
- Williams, J. G. & Harper, C. T., 1978. Age and status of the Mackay Intrusives in the Eglinton-upper Hollyford area. *New Zealand Journal of Geology and Geophysics.* vol. 21, No. 6, p. 733-742.
- Willsman, A., 1990. Stratigraphy, Tectonics and Provenance of rocks in the Wether Hill Area, Western Southland. *BSc Honours Thesis (unpublished).*
- Wilson, M. ,1989. Igneous Petrogenesis: A Global Tectonic Approach. *London Unwin Hyman.* 466 pp.
- Wood, B. L., 1959. The Geology of the Gore Subdivision. *New Zealand Geological Survey Bulletin n.s.* 53.

Appendix A.

PETROGRAPHIC NOTES & DESCRIPTIONS

Takitimu Group Volcanics

OU 63926 BASALTIC-ANDESITE

Intensely altered melanocratic rock containing very altered euhedral plagioclase, fractured subhedral augite and irregular magnetite phenocrysts. Some augite phenocrysts sub-ophytically enclose plagioclase microphenocrysts. The groundmass is dominant and consists of plagioclase, augite, magnetite, apatite and minor amounts of quartz. Chloritisation is pervasive as is laumontite. Laumontite is so abundant that it gives a hand specimen a pinkish look to it.

OU 63927 BASALTIC-ANDESITE

A fine grained groundmass (avg. 0.03 mm) dominates over phenocryst phases and consists of tiny augite crystals, acicular and skeletal plagioclase and small subhedral magnetite. Phenocryst (avg. 0.6 mm) phases include intensely sericitised plagioclase, huge (1.1 mm) augite crystals and magnetite. Laumontite occurs throughout the rock along with small amounts of glass. The zeolite mordenite was found, by XRD, to occur within larger (2 cm) veins which penetrate the outcrop.

OU 63928 BASALTIC-ANDESITE

Fine grained (avg. 0.2 mm) melanocratic rock with rare euhedral sericitised plagioclase phenocrysts (0.9 mm). Altered plagioclase laths dominate the groundmass and subhedral augite crystals are also common. Magnetite generally occurs as small euhedral grains but in some regions of the rock they form dense clusters of acicular 'birdsfoot' textures all massed together. Chlorite together with thomsonite are the alteration and metamorphic minerals present, respectively.

OU 63929, OU 63930 BASALTIC-ANDESITE

Melanocratic rock dominated by equal proportions of sericitised plagioclase and augite with less magnetite in the groundmass (avg. 0.2 mm). Euhedral plagioclase is the dominant phenocryst (avg. 1.0 mm) phase and usually occurs in glomeroporphyritic association with one another. Skeletal magnetite phenocrysts are also present. Heulandite and quartz occur within the voids and prehnite forms within microscopic veins. Chlorite is an abundant alteration product and may some times form the lining to amygdales which are infilled by heulandite.

OU 63931 PORPHYRITIC BASALTIC-ANDESITE

A mesocratic basalt containing abundant large (avg. 1.5 mm) sub-anhedral plagioclase and highly fractured augite phenocrysts. Many of the

plagioclase phenocrysts are complexly zoned and concentrically altered by sericite. Almost all the augite phenocrysts are sub-ophytically and ophytically overgrown by anhedral magnetite grains. The groundmass consists dominantly of fine grained sub-euhedral magnetite grains surrounded by intensely altered plagioclase. Apatite laths are also present within the groundmass.

OU 18.19 SJM BASALT

A melanocratic, porphyritic basalt with a very fine grained, intensely altered groundmass consisting of sericitised plagioclase, tiny augite, magnetite and apatite crystals. Phenocrysts (avg. 0.3 mm) are dominated by oscillatory zoned, glomeroporphyritic, subhedral augite. Plagioclase is absent as a phenocryst phase as is magnetite. Chlorite has replaced glomeroporphyritic olivine phenocrysts throughout the sample.

OU 63932 PORPHYRITIC BASALTIC-ANDESITE

Meso-melanocratic porphyritic rock containing abundant plagioclase phenocrysts (avg. 0.6 mm). Olivine, now replaced by chlorite and chlorite-vermiculite, was once one of the phenocryst phases as is augite. Some augite phenocrysts have a rounded resorption texture at their boundaries. The groundmass (avg. 0.02 mm) contains magnetite and plagioclase laths which sometimes have pilotaxitic textures. Chlorite only occurs as an alteration product.

White Hill Intrusive Suite

OU 63914 MICROGABBRO:

A mesocratic, equigranular rock with a hypidiomorphic texture. The dominant phases include highly sericitised plagioclase phenocrysts, comparatively fresh pale green augite phenocrysts and subhedral magnetite. Also contains abundant chlorite, chlorite-vermiculite alteration, calcite and laumontite.

OU 63915 BASALT:

Altered plagioclase and fresher diopside and augite phenocrysts (avg. 1.5 mm) occur within a dominating groundmass (avg. 0.2 mm) consisting of skeletal plagioclase, clinopyroxene and fine acicular radiating magnetite crystals. Thomsonite and gonnardite infill amygdales and celadonite is also present.

OU 63916 MICROGABBRO:

Medium grained mesocratic rock very similar to OU 1. SJM. Contains skeletal magnetite grains and the odd patch of brown glass in association with augite. Analcime, heulandite and prehnite are also present along with chloritic alteration products.

OU 63917 & OU 63918 MICROGABBRO:

Medium grained rock containing sericitised plagioclase, equant sub-euhedral augite and subhedral magnetite. Contains much chlorite and chlorite-vermiculite.

OU 63919 & OU 63920 GABBRO:

Medium (1.1 mm) crystalline, mesocratic rock containing altered plagioclase, glomeroporphyritic augite, rare orthopyroxene, and partially resorbed, skeletal magnetite. Has alteration of what once may have been olivine.

OU 63921 & OU 63922 COARSE GRAINED BASALT:

Fine to medium grained crystalline rock containing glomeroporphyritic, zoned augite as the dominant phenocryst (avg. 0.6 mm) phase. Subordinate magnetite and plagioclase also occur as phenocrysts. Contains a few grains of the red coloured titanium-rich biotite. Skeletal plagioclase occurs within the groundmass (avg. 0.06 mm) along with a lot of chloritic alteration. Chlorite-vermiculite may be replacing olivine phenocrysts. Laumontite and prehnite are also present in this rock.

OU 63923 MICROGABBRO

A medium rock dominated by the groundmass (avg. 0.24 mm) phases, namely skeletal plagioclase, magnetite and augite. Phenocrysts phases include sericitised plagioclase, ferrian and ferrian aluminum-bearing augite along with skeletal magnetite. Orthopyroxene is very rare. Some of the augite phenocrysts have partially resorbed rims and other phenocrysts may be > 5 mm in diameter. A single ferri-tschermakitic hornblende megacryst with a rounded edges and a sort of resorption rim is also present within this sample. Chlorite-vermiculite is a common olivine-replacement mineral along with chlorite.

Layered White Hill Intrusive

OU 63924 SJM GABBRO

A comparatively fresh mesocratic crystalline rock containing abundant plagioclase phenocrysts with little clinopyroxene and magnetite phenocryst phases. Groundmass phases are subordinate to phenocrysts and include mainly plagioclase with magnetite and rare clinopyroxene. Chlorite is an abundant alteration product, and very little-no zeolite is present.

OU 63925 SJM GABBRO

Intensely altered melanocratic rock consisting entirely of phenocryst phases and metamorphic and alteration minerals. Intensely sericitised, chloritised and fractured plagioclase is the dominant mineral. Clinopyroxene is sometimes zoned and is only present in small amounts along with skeletal magnetite. Chlorite is an abundant alteration product. Laumontite is also

abundant, generally between phenocrysts and is often interwoven with bright green chlorite. Olivine may have once been present within the rock but is now replaced by chloritic minerals.

DETAILED DESCRIPTIONS

Takitimu Group Volcanic

Specimen No: OU 63971

Grid Reference: 145735

Macroscopic Description:

In hand specimen this rock is dark coloured and contains feldspar phenocrysts along with greeny-black pyroxenes.

Microscopic Description:

This is a melanocratic, porphyritic rock consisting of plagioclase and pyroxene phenocrysts in a fine grained groundmass of plagioclase, pyroxene and opaque minerals. There is a very high proportion of opaques in the groundmass giving a dark appearance. The plagioclase in the groundmass is often preferentially oriented, ie; has a pilotaxitic texture. The plagioclase phenocryst phase is very much dominant over the clinopyroxene phenocrysts. Chlorite can be seen throughout the thin-section possibly replacing what once was olivine. Many of the chlorite replacements contain dark glomeroporphyritic aggregates of titanite. There may also be tiny veins of prehnite.

Brief Description of Constituent Minerals:

Plagioclase (75%) occurs in both the groundmass and as phenocrysts in high proportions, that is it is the dominant phase. They are generally euhedral laths. In the groundmass they are almost acicular. The phenocrysts show normal zoning and have an anorthite content of 63-67% indicating labradorite.

Clinopyroxene (10%), probably augite, is rare in the phenocryst form but is abundant in the groundmass. The few phenocrysts that are present are generally euhedral and seem to have a sort of reaction rim. One in particular is very rounded, perhaps due to resorption, and has a reaction rim surrounding it. In the groundmass they occur as tiny euhedral crystals in an intergranular relationship with plagioclase laths. The clinopyroxene phenocrysts are sometimes twinned.

Opaques (8%) are dominant in the groundmass but they do not occur in the phenocryst phase. They occur along with clinopyroxene in an

intergranular texture. Opaques also occur enclosed within the plagioclase phenocrysts.

Chlorite (5%) occurs as a replacement mineral, perhaps replacing olivine, as indicated by the subhedral form typical of olivine and the heavy cracks.

Accessory Phases (2%) include titanite, which occurs enclosed within the chlorite replacement, perhaps they were originally enclosed in the olivines. Also small amounts of acicular apatite occur within the groundmass.

Classification: 'Olivine' Basalt.

White Hill Intrusive

Specimen No: OU 63914

Grid Reference: 130746

Macroscopic Description:

This is a mesocratic, equigranular rock with grains between 1 mm and 5 mm (medium grained). In hand specimen black specs of an opaque (magnetite) mineral are visible along with sugary white plagioclase and greenish pyroxene. In outcrop this rock is intensely veined with the zeolite, laumontite.

Microscopic Description:

In thin-section this rock possesses a hypidiomorphic texture. Plagioclase crystals are intensely sericitised but the pyroxenes are comparatively unaltered. An opaque mineral, probably magnetite due to its cubic form, is another dominant phase. Alteration products include minor amounts of pale green chlorite, identified by its anomalous blue colour under crossed polars. There is also a brown (under plane polarised light) pseudomorph of chlorite.

Brief Description of Constituent Minerals:

Plagioclase (65%) is very difficult to identify due to its intense sericitisation. This alteration seems to be replacing the plagioclase from the outside towards the center. Sericite often forms zonal bands within the plagioclase, this may be a preferential alteration in Ca-rich zones. An anorthite composition is too difficult to obtain optically because of the alteration.

Clinopyroxene (25%) occurs as subhedral, pale green crystals, and is probably the mineral augite. Most show the distinctive oblique extinction pattern. The ones that show a straight extinction are viewed down the b-axis. All crystals show some degree of fracturing and a few contain kink bands. Some grains have pieces missing while others contain replacement minerals such as chlorite-vermiculite or zeolite. Many of the augite grains

have magnetite in close association, and in some cases magnetite occurs as an ophitic overgrowth.

Magnetite: (5%) occurs as sub-euhedral crystals which generally have the characteristic cubic form. They are generally <1 mm (medium to fine grained) and occur evenly throughout the slide. Some crystals are ophitically enclosed within pyroxene.

Alteration Products: (3%) include pale green, sometimes acicular crystals of chlorite, the brownish-green chlorite-vermiculite which forms radiating, acicular clusters. In both cases these minerals seem to be replacing clinopyroxene.

Accessory Minerals: (2%) such as apatite occur as very long and thin needles indicating under cooling conditions of crystallisation. Laumontite, also occurs in very small quantities. Because of their very small size they are very hard to identify. Prehnite is also present showing its characteristic length fast nature.

Classification:

Due to the medium, equigranular nature of the rock and in the absence of hornblende, this rock is a microgabbro rather than a diorite.

Appendix B.

XRF ANALYSES

Major and trace elements were analysed in the Geology Dept., University of Otago using a Phillips PW1410 XRF spectrometer. Major element analyses were made on an oven dry (110°C) basis, and total volatile losses (LOI=loss on ignition) was determined by the ignition of samples for two hours in air at 1100°C. Trace element determinations were done on press powder pellets, made by adding 5 ml of binding agent to crushed powder and compressing in a hydraulic press.

Data which gave totals of less than 99.0 % and greater than 101.5 % were not used in the study for analytical techniques.

XRF ANALYSES

XRF ANALYSES FOR IGNEOUS LITHOLOGIES OF THE TAKITIMU GROUP

Major Element Wt %	OU 63926	OU63931	OU63932	OU63927	OU63928	OU63953
SiO2	53.92	55.81	54.95	52.96	53.03	52.81
TiO2	1.39	0.62	0.78	0.5	1.29	0.98
Al2O3	14.56	17.22	17.79	15.81	14.64	16.64
Fe2O3	4.27	2.75	2.58	2.94	4.31	3.27
FeO	6.40	4.12	3.88	4.41	6.47	4.90
MnO	0.19	0.14	0.11	0.14	0.21	0.15
MgO	3.95	6.54	2.44	7.55	3.72	2.85
CaO	4.81	6.67	7.71	9.69	6.35	7.42
Na2O	7.47	5.25	5.24	3.14	4.63	5.45
K2O	1.14	2.11	0.89	0.37	0.6	0.43
P2O5	0.3	0.22	0.23	0.14	0.31	0.31
LOI	2.74	1.98	2.69	2.21	3.86	4.69
TOTAL	101.15	100.43	99.3	99.86	99.43	99.89
Trace Elements(ppm)						
Ga	20	22	20	18	17	22
Rb	15	33	11	8	16	7
Sr	229	766	810	447	369	165
Y	29	20	25	11	33	23
Zr	106	81	128	42	125	93
Pb	5	7	6	4	4	4
Th	2	0	3	1	1	1
U	3	0	1	1	2	1
Ni	16	N.D.	15	60	12	11
Cu	165	N.D.	108	150	165	159
Zn	107	N.D.	60	61	90	73
Nb	1	N.D.	1	1	0	1
V	357	222	199	258	306	232
Cr	9	7	18	155	3	8
Ba	78	180	61	22	53	9
La	5	10	11	6	6	7
Ce	19	14	25	4	23	19
Pr	9	5	6	4	10	7
Nd	18	21	20	8	21	19
A=(Na2O +K2O)	8.61	7.36	6.13	3.51	5.23	5.88
F=(FeO+ Fe2O3)	11.38	2.75	2.58	2.94	4.31	3.27
M=(MgO)	3.95	6.54	2.44	7.55	3.72	2.85
Total	23.94	16.65	11.15	14.00	13.26	12.00
A	36	35	40	19	26	34
F	48	34	45	41	56	50
M	16	31	15	40	18	16
FeO*/MgO	2.70	1.05	2.65	0.97	2.90	2.86
#1. A.I	4.64	3.38	3.02	2.07	3.07	3.53
TiO2	22	15	19	15	20	18
MnO*10	30	33	26	42	32	27
P2O5*10	48	52	55	43	48	55
#2. Ti/100	30	21	19	29	26	27
Zr	38	46	51	40	42	42
Y*3	32	23	30	31	32	31

N.D.=Not Determined

#1. A.I=(Na2O+K2O)/(SiO2-43)*0.17

#2. ppm Ti=(TiO2*0.5994081)*10000

XRF ANALYSES

XRF ANALYSES FOR VOLCANICLASTICS OF THE TAKITIMU GROUP

Major Element Wt %	OU 63947	OU 63954	OU 63937	OU 63955	OU 63944	OU 63956	OU 63940	OU 63948
SiO ₂	52.18	53.43	53.58	51.38	49.46	51.69	49.47	N.D.
TiO ₂	0.89	1.08	0.75	0.96	1.06	0.89	1.63	N.D.
Al ₂ O ₃	15.84	14.88	17.75	16.85	15.9	15.91	17.39	N.D.
Fe ₂ O ₃	3.90	3.55	3.14	3.78	3.72	3.36	3.81	N.D.
FeO	5.86	5.33	4.71	5.66	5.58	5.03	5.71	N.D.
MnO	0.18	0.16	0.16	0.14	0.18	0.17	0.17	N.D.
MgO	4.54	3.58	3.63	3.63	4.52	4.14	5.46	N.D.
CaO	7.97	8.08	5.08	7.96	6.64	8.03	8.8	N.D.
Na ₂ O	3.76	3.21	5.72	4.86	5.31	3.99	3.21	N.D.
K ₂ O	0.81	0.74	1.31	1.8	1.06	1.2	1.39	N.D.
P ₂ O ₅	0.18	0.37	0.17	0.18	0.24	0.21	0.19	N.D.
LOI	4.15	6.31	4.70	2.62	6.49	5.21	2.78	N.D.
TOTAL	100.26	100.73	100.7	99.84	100.15	99.83	100.02	N.D.
Trace Elements (ppm)								
Ga	18	18	18	21	17	18	22	26
Rb	12	10	23	49	15	18	41	5
Sr	1372	3162	848	1050	1784	154	587	38
Y	23	32	24	22	26	21	19	11
Zr	85	130	82	64	96	94	69	50
Pb	6	9	4	4	7	11	2	5
Th	0	0	0	0	0	0	2	1
U	0	0	1	0	0	0	3	2
Ni	24	18	18	16	18	26	26	13
Cu	121	173	53	85	92	61	64	70
Zn	96	82	64	63	84	112	68	55
Nb	0	0	1	0	1	2	1	0
V	282	239	181	257	276	227	346	139
Cr	41	24	24	21	25	63	35	14
Ba	81	76	121	91	87	80	100	0
La	4	11	5	0	5	7	5	3
Ce	9	35	15	9	21	10	12	7
Pr	8	8	8	9	6	4	4	2
Nd	15	27	12	10	14	17	15	9
A=(Na ₂ O + K ₂ O)	4.57	3.95	7.03	6.66	6.37	5.19	4.6	-
F=(FeO + Fe ₂ O ₃)	10.41	3.55	3.14	3.78	3.72	3.36	3.81	-
M=(MgO)	4.54	3.58	3.63	3.63	4.52	4.14	5.46	-
Total	19.52	11.08	13.80	14.07	14.61	12.69	13.87	-
A	24	23	37	33	31	28	23	-
F	53	56	44	49	48	49	50	-
M	23	21	19	18	21	23	27	-
FeO*/MgO	2.15	2.48	2.16	2.60	2.06	2.03	1.74	-
#1. A.I	2.93	2.23	3.91	4.67	5.80	3.51	4.18	-
TiO ₂	20	17	18	23	20	19	31	-
MnO*10	40	25	39	34	34	36	33	-
P ₂ O ₅ *10	40	58	43	43	46	45	36	-
#2. Ti/100	26	22	23	30	27	25	44	-
Zr	41	45	41	34	40	45	31	-
Y*3	33	33	36	36	33	30	25	-

N.D.=Not Determined

#1. A.I=(Na₂O+K₂O)/(SiO₂-43)*0.17#2. ppm Ti=(TiO₂*0.5994081)*10000

XRF ANALYSES

XRF ANALYSES FOR THE WHITE HILL INTRUSIVE SUITE

Major Element Wt %	OU 63915	OU 63914	OU 63921	OU 63919	OU 63923	OU 63958	OU 63922	OU 63920
SiO ₂	52.08	51.77	47.48	48.54	49.15	48.53	47.84	48.37
TiO ₂	0.95	0.9	0.88	0.95	0.62	0.87	0.92	1.06
Al ₂ O ₃	16.37	16.19	14.11	18.04	18.11	14.46	14.17	17.28
Fe ₂ O ₃	3.48	3.55	3.92	3.52	3.45	3.56	4.08	3.82
FeO	5.22	5.32	5.88	5.29	5.18	5.34	6.11	5.74
MnO	0.16	0.18	0.18	0.15	0.15	0.16	0.2	0.16
MgO	4.12	4.13	8.4	4.49	5.81	8.22	8.49	4.71
CaO	7.55	6.91	12.06	9.43	9.78	9.93	11.2	9.22
Na ₂ O	4.6	4.69	4.83	5.51	4.88	4.92	4.03	5.94
K ₂ O	1	1.42	0.75	1.49	0.87	1.1	0.83	1.66
P ₂ O ₅	0.29	0.26	0.21	0.31	0.2	0.25	0.21	0.34
LOI	3.64	3.96	2.59	3.06	2.42	3.72	2.86	2.85
TOTAL	99.47	99.29	101.3	100.78	100.61	101.06	100.95	101.14
Trace Elements (ppm)								
Ga	21	20	18	19	19	16	13	21
Rb	21	25	16	31	15	17	18	32
Sr	927	562	698	935	466	334	687	983
Y	23	23	18	18	12	19	18	20
Zr	107	101	54	85	38	71	57	86
Pb	7	40	3	5	5	5	3	2
Th	2	1	1	0	1	0	0	1
U	2	1	1	0	1	1	1	0
Ni	16	16	59	37	34	78	56	35
Cu	151	108	86	164	56	101	104	147
Zn	77	68	55	55	54	52	59	55
Nb	0	2	0	1	0	0	0	3
V	264	217	232	311	279	258	241	369
Cr	38	15	245	34	60	274	246	28
Ba	76	102	45	90	56	85	55	106
La	8	8	7	12	5	3	7	17
Ce	21	17	10	36	12	9	15	34
Pr	10	7	6	6	7	14	6	5
Nd	18	20	18	22	12	12	18	24
A=(Na ₂ O + K ₂ O)	5.6	6.11	5.58	7	5.75	6.02	4.86	7.6
F=(FeO + Fe ₂ O ₃)	9.28	9.46	3.92	3.52	3.45	3.56	4.08	3.82
M=(MgO)	4.12	4.13	8.4	4.49	5.81	8.22	8.49	4.71
Total	19	19.7	17.90	15.01	15.01	17.80	17.43	16.13
A	30	31	23	33	28	25	20	34
F	49	48	43	45	44	40	45	45
M	21	21	34	22	28	35	35	21
FeO*/MgO	2.11	2.15	1.17	1.96	1.49	1.08	1.20	2.03
#1. A.I	3.63	4.10	7.33	7.43	5.50	6.40	5.91	8.33
TiO ₂	18	17	18	17	15	17	18	18
MnO*10	29	34	38	27	36	32	40	26
P ₂ O ₅ *10	53	49	44	56	49	51	42	56
#2. Ti/100	24	24	33	29	33	29	33	30
Zr	46	45	33.5	43	34	40	34	41
Y*3	30	31	33.5	28	33	31	33	29

#1. A.I=(Na₂O+K₂O)/(SiO₂-43)*0.17#2. ppm Ti=(TiO₂*0.5994081)*10000

XRF ANALYSES

XRF ANALYSES FOR THE WHITE HILL INTRUSIVE SUITE continued...

Major Element Wt %	OU 63916	OU 63917	OU 63918
SiO2	51.83	52.09	52.01
TiO2	0.9	0.87	0.92
Al2O3	16.16	14.56	16.44
Fe2O3	3.38	3.94	3.72
FeO	5.07	5.92	5.58
MnO	0.17	0.22	0.18
MgO	4.17	6.53	4.85
CaO	8.07	10.18	8.47
Na2O	5.83	2.66	4.04
K2O	1.28	0.8	1.01
P2O5	0.23	0.17	0.24
LOI	3.81	1.69	2.74
TOTAL	100.9	99.64	100.2
Trace Elements (ppm)			
Ga	18	23	20
Rb	24	12	15
Sr	515	338	543
Y	25	28	23
Zr	102	121	98
Pb	3	3	3
Th	2	1	0
U	2	2	0
Ni	25	43	18
Cu	23	105	103
Zn	53	66	64
Nb	0	1	0
V	235	265	231
Cr	45	91	22
Ba	84	62	68
La	5	8	7
Ce	13	15	21
Pr	6	6	8
Nd	18	18	16
A=(Na2O +K2O)	7.11	3.46	5.05
F=(FeO+ Fe2O3)	3.38	3.94	3.72
M=(MgO)	4.17	6.53	4.85
Total	14.66	13.93	13.62
A	35	17	26
F	44	51	50
M	21	32	24
FeO*/MgO	2.03	1.51	1.92
#1. A.I	4.74	2.24	3.30
TiO2	18	18	18
MnO*10	35	46	35
P2O5*10	47	36	47
#2. Ti/100	23	20	25
Zr	44	47	44
Y*3	33	33	31

#1. A.I=(Na2O+K2O)/(SiO2-43)*0.17

#2. ppm Ti=(TiO2*0.5994081)*10000

Appendix C. MICROPROBE ANALYSES

All electron microprobe analyses were carried out on the SuperProbe JXA-8600 at the University of Otago. Analyses for plagioclase, pyroxene, and amphibole (see text) analyses were only accepted if they had totals of between 98.0 and 102.0 %. Magnetite totals were accepted from about 93 % to 102 % (see text)

Plagioclase

WHITE HILL PLAGIOCLASE COMPOSITIONS

	OU 63916	OU 63917	OU 63917	OU 63917	OU 63917	OU 63923	OU 63923	OU 63923
Phenocrysts	Core	Core	Core	Rim	Core	Rim	Core	Rim
SiO2	62.86	53.47	47.86	53.17	52.25	46.99	45.35	46.14
Al2O3	25.20	28.92	32.19	28.96	29.51	34.12	34.83	33.79
TiO2	0.00	0.04	0.02	0.04	0.05	0.00	0.00	0.00
FeO	0.69	0.96	0.85	0.81	0.91	0.64	0.67	0.72
MnO	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00
MgO	0.26	0.12	0.07	0.12	0.13	0.06	0.04	0.00
CaO	4.26	13.40	17.33	13.71	14.54	16.73	19.25	18.34
Na2O	7.89	4.39	1.77	4.31	3.92	1.24	0.61	1.06
K2O	0.05	0.16	0.04	0.12	0.11	0.06	0.03	0.02
Cr2O3	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NiO	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
TOTAL	101.23	101.46	100.16	101.27	101.42	99.86	100.78	100.07
Cations on bases of 32 oxygen atoms								
Si	10.96	9.62	8.81	9.59	9.44	8.64	8.33	8.52
Al	5.18	6.14	6.99	6.16	6.28	7.39	7.55	7.36
Ti	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00
Fe	0.10	0.14	0.13	0.12	0.14	0.10	0.10	0.11
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg	0.07	0.03	0.02	0.03	0.03	0.02	0.01	0.00
Ca	0.80	2.58	3.42	2.65	2.81	3.29	3.79	3.63
Na	2.67	1.53	0.63	1.51	1.37	0.44	0.22	0.38
K	0.01	0.04	0.01	0.03	0.03	0.01	0.01	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	19.79	20.09	20.02	20.10	20.11	19.90	20.01	20.00
Ca	22.91	62.23	84.21	63.32	66.81	87.81	94.42	90.48
Na	76.77	36.89	15.56	36.02	32.59	11.81	5.38	9.43
K	0.32	0.88	0.23	0.66	0.60	0.38	0.19	0.10

TAKITIMU GROUP VOLCANIC PYROXENE COMPOSITIONS & NAMES

Sample	OU 63927	OU 63927	OU 63928	OU 63928	OU 63928	OU 63931	OU 63931
	Core	Rim	Core	-	Rim	Rim	Core
SiO2	52.13	52.71	51.88	50.91	51.19	54.57	52.74
Al2O3	2.83	2.37	5.40	4.05	3.63	1.49	2.91
TiO2	0.22	0.24	1.12	0.98	0.92	0.38	0.38
FeO*	5.90	6.75	9.70	10.91	10.16	8.22	10.40
MnO	0.18	0.16	0.28	0.33	0.22	0.35	0.34
MgO	16.81	17.56	13.43	14.24	14.16	16.45	15.00
CaO	20.54	20.19	18.16	18.43	19.27	19.03	18.57
Na2O	0.23	0.15	0.26	0.37	0.26	0.20	0.43
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Cr2O3	0.11	0.16	0.00	0.00	0.03	0.00	0.00
NiO	0.04	0.00	0.00	0.00	0.00	0.04	0.00
ZrO2							
V2O3							
Sc2O3							
Li2O							
Total	98.99	100.29	100.23	100.22	99.84	100.73	100.77
Recalculated							
Fe2O3	1.04	1.70	0.00	0.23	0.00	0.00	0.00
FeO	4.96	5.22	9.70	10.71	10.16	8.22	10.40
Total	99.09	100.46	100.23	100.24	99.84	100.73	100.77
Cations							
Si	1.925	1.922	1.909	1.894	1.909	1.989	1.943
Al	0.123	0.102	0.234	0.178	0.160	0.064	0.126
Ti	0.006	0.007	0.031	0.027	0.026	0.010	0.011
Fe3+	0.029	0.047		0.006			
Fe2+	0.153	0.159	0.298	0.333	0.317	0.251	0.320
Mn	0.006	0.005	0.009	0.010	0.007	0.011	0.011
Mg	0.925	0.955	0.737	0.790	0.787	0.894	0.824
Ca	0.812	0.789	0.716	0.735	0.770	0.743	0.733
Na	0.016	0.011	0.019	0.027	0.019	0.014	0.030
K							0.001
Cr	0.003	0.005			0.001		
Ni	0.001					0.001	
Total	4.000	4.000	3.952	4.000	3.995	3.976	3.999
Ideal Site Occupancy							
Si	1.925	1.922	1.909	1.894	1.909	1.989	1.943
Al iv	0.075	0.078	0.091	0.106	0.091	0.011	0.057
Fe3 iv							
T site =	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Al vi	0.048	0.024	0.143	0.072	0.068	0.053	0.069
Fe3 vi	0.029	0.047		0.006			
Ti	0.006	0.007	0.031	0.027	0.026	0.010	0.011
Cr	0.003	0.005			0.001		
Ni	0.001					0.001	
Mg	0.913	0.918	0.737	0.790	0.787	0.894	0.824
Fe2			0.089	0.105	0.118	0.042	0.096
Mn			0.009	0.010	0.007	0.011	0.011
M1 site =	1.000	1.000	1.009	1.010	1.007	1.011	1.011
Mg	0.012	0.037					
Fe2	0.153	0.159	0.209	0.228	0.199	0.208	0.224
Mn	0.006	0.005					
Li							
K							0.001
Ca	0.812	0.789	0.716	0.735	0.770	0.743	0.733
Na	0.016	0.011	0.019	0.027	0.019	0.014	0.030
M2 site =	1.000	1.000	0.944	0.990	0.988	0.965	0.988
Chemical							
Group	Quad	Quad	Quad	Quad	Quad	Quad	Quad
Calculated							
Name	augite	augite	aluminian augite	augite	augite	augite	augite

Sample	OU 63931	OU 63931	OU 63931	OU 63930	OU 63930	OU 63933
	Rim	Rim	Core	Core	Core	Core
SiO2	54.27	51.43	52.62	49.37	52.83	49.64
Al2O3	2.16	2.30	3.22	2.44	2.06	5.15
TiO2	0.27	0.52	0.66	1.25	0.62	0.60
FeO*	7.75	7.50	8.17	18.49	10.22	7.21
MnO	0.27	0.27	0.39	0.55	0.41	0.12
MgO	14.70	15.06	13.92	11.18	14.84	14.67
CaO	20.71	21.64	19.80	16.73	19.65	22.11
Na2O	0.48	0.28	0.23	0.30	0.23	0.21
K2O	0.00	0.00	0.00	0.00	0.00	0.00
Cr2O3	0.00	0.00	0.02	0.02	0.00	0.50
NiO	0.00	0.07	0.00			0.00
ZrO2						
V2O3						
Sc2O3						
Li2O						
Total	100.61	99.07	99.02	100.34	100.86	100.21
Recalculated						
Fe2O3	0.00	1.94	0.00	1.81	0.00	3.21
FeO	7.75	5.75	8.17	16.86	10.22	4.32
Total	100.61	99.26	99.02	100.52	100.86	100.53
Cations						
Si	1.985	1.918	1.957	1.893	1.950	1.827
Al	0.093	0.101	0.141	0.110	0.090	0.223
Ti	0.007	0.015	0.018	0.036	0.017	0.017
Fe3+		0.054		0.052		0.089
Fe2+	0.237	0.179	0.254	0.541	0.315	0.133
Mn	0.009	0.009	0.012	0.018	0.013	0.004
Mg	0.801	0.837	0.772	0.639	0.817	0.805
Ca	0.812	0.865	0.789	0.687	0.777	0.872
Na	0.034	0.020	0.017	0.022	0.016	0.015
K						
Cr			0.001	0.001		0.015
Ni		0.002				
Total	3.978	4.000	3.962	4.000	3.996	4.000
Ideal Site Occu						
Si	1.985	1.918	1.957	1.893	1.950	1.827
Al iv	0.015	0.082	0.043	0.107	0.050	0.173
Fe3 iv						
T site =	2.000	2.000	2.000	2.000	2.000	2.000
Al vi	0.078	0.019	0.099	0.004	0.040	0.051
Fe3 vi		0.054		0.052		0.089
Ti	0.007	0.015	0.018	0.036	0.017	0.017
Cr			0.001	0.001		0.015
Ni		0.002				
Mg	0.801	0.837	0.772	0.639	0.817	0.805
Fe2	0.113	0.073	0.110	0.268	0.126	0.024
Mn	0.009	0.009	0.012	0.018	0.013	0.004
M1 site =	1.009	1.009	1.012	1.018	1.013	1.004
Mg						
Fe2	0.124	0.106	0.144	0.273	0.189	0.109
Mn						
Li						
K						
Ca	0.812	0.865	0.789	0.687	0.777	0.872
Na	0.034	0.020	0.017	0.022	0.016	0.015
M2 site =	0.970	0.991	0.949	0.982	0.983	0.996
Chemical						
Group	Quad	Quad	Quad	Quad	Quad	Quad
Calcaluated						
Name	augite	augite	augite	augite	augite	chromian diopside

Sample	OU 63933	OU 63933	OU 63933	OU 63933	OU 63933	OU 63933
	Rim	Core	-	Core	Rim	-
SiO ₂	49.01	51.11	52.46	51.78	51.77	51.63
Al ₂ O ₃	5.64	4.13	3.15	3.10	3.62	3.51
TiO ₂	0.72	0.40	0.33	0.44	0.43	0.45
FeO*	9.13	6.61	4.98	8.37	7.08	6.82
MnO	0.13	0.17	0.10	0.17	0.17	0.11
MgO	14.35	15.51	16.46	15.45	15.75	15.49
CaO	20.44	22.60	22.53	20.97	21.80	21.82
Na ₂ O	0.32	0.20	0.20	0.25	0.25	0.21
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00
Cr ₂ O ₃	0.17	0.02	0.68	0.03	0.23	0.30
NiO	0.00	0.05	0.07	0.08	0.04	0.00
ZrO ₂						
V ₂ O ₃						
Sc ₂ O ₃						
Li ₂ O						
Total	99.91	100.80	100.96	100.64	101.14	100.34
Recalculated						
Fe ₂ O ₃	3.62	3.21	1.40	2.08	2.41	1.48
FeO	5.87	3.72	3.72	6.50	4.92	5.49
Total	100.27	101.12	101.10	100.85	101.38	100.49
Cations						
Si	1.815	1.863	1.902	1.901	1.883	1.894
Al	0.246	0.177	0.135	0.134	0.155	0.152
Ti	0.020	0.011	0.009	0.012	0.012	0.012
Fe ³⁺	0.101	0.088	0.038	0.058	0.066	0.041
Fe ²⁺	0.182	0.114	0.113	0.199	0.150	0.168
Mn	0.004	0.005	0.003	0.005	0.005	0.003
Mg	0.792	0.843	0.890	0.845	0.854	0.847
Ca	0.811	0.883	0.875	0.825	0.850	0.858
Na	0.023	0.014	0.014	0.018	0.018	0.015
K						
Cr	0.005	0.001	0.019	0.001	0.007	0.009
Ni		0.001	0.002	0.002	0.001	
Total	4.000	4.000	4.000	4.000	4.000	4.000
Ideal Site Occu]						
Si	1.815	1.863	1.902	1.901	1.883	1.894
Al _{iv}	0.185	0.137	0.098	0.099	0.117	0.106
Fe _{3 iv}						
T site =	2.000	2.000	2.000	2.000	2.000	2.000
Al _{vi}	0.062	0.041	0.037	0.035	0.038	0.046
Fe _{3 vi}	0.101	0.088	0.038	0.058	0.066	0.041
Ti	0.020	0.011	0.009	0.012	0.012	0.012
Cr	0.005	0.001	0.019	0.001	0.007	0.009
Ni		0.001	0.002	0.002	0.001	
Mg	0.792	0.843	0.890	0.845	0.854	0.847
Fe ₂	0.020	0.016	0.005	0.047	0.022	0.045
Mn	0.004	0.005	0.003	0.005	0.005	0.003
M1 site =	1.004	1.005	1.003	1.005	1.005	1.003
Mg						
Fe ₂	0.162	0.098	0.108	0.152	0.127	0.124
Mn						
Li						
K						
Ca	0.811	0.883	0.875	0.825	0.850	0.858
Na	0.023	0.014	0.014	0.018	0.018	0.015
M2 site =	0.996	0.995	0.997	0.995	0.995	0.997
Chemical						
Group	Quad	Quad	Quad	Quad	Quad	Quad
Calculated						
Name	ferrian augite	diopside	chromian diopside	augite	augite	augite

Sample	OU 63933	OU 63933	OU 63933	OU 63933	OU 63933	OU 63933
	-	Core	Rim	-	-	Core
SiO ₂	49.40	50.42	51.38	51.61	51.74	50.48
Al ₂ O ₃	4.61	4.52	3.57	3.54	3.52	4.37
TiO ₂	0.78	0.58	0.47	0.42	0.44	0.55
FeO*	10.92	8.06	8.58	5.78	7.46	6.55
MnO	0.13	0.11	0.11	0.06	0.06	0.10
MgO	14.39	14.68	15.85	15.88	15.54	14.69
CaO	19.84	21.97	20.75	21.70	21.81	22.07
Na ₂ O	0.43	0.24	0.25	0.28	0.27	0.25
K ₂ O	0.00	0.00	0.00	0.00	0.00	0.00
Cr ₂ O ₃	0.07	0.19	0.17	0.23	0.25	0.18
NiO	0.00	0.00	0.00	0.00	0.00	0.00
ZrO ₂						
V ₂ O ₃						
Sc ₂ O ₃						
Li ₂ O						
Total	100.57	100.77	101.13	99.50	101.09	99.24
Recalculated						
Fe ₂ O ₃	4.83	3.10	3.14	1.29	2.39	1.57
FeO	6.58	5.27	5.75	4.62	5.31	5.13
Total	101.05	101.08	101.45	99.63	101.33	99.40
Cations						
Si	1.825	1.849	1.874	1.900	1.885	1.873
Al	0.201	0.195	0.153	0.154	0.151	0.191
Ti	0.022	0.016	0.013	0.012	0.012	0.015
Fe ³⁺	0.134	0.086	0.086	0.036	0.066	0.044
Fe ²⁺	0.203	0.162	0.175	0.142	0.162	0.159
Mn	0.004	0.003	0.003	0.002	0.002	0.003
Mg	0.793	0.803	0.862	0.872	0.844	0.813
Ca	0.785	0.863	0.811	0.856	0.852	0.878
Na	0.031	0.017	0.018	0.020	0.019	0.018
K						
Cr	0.002	0.006	0.005	0.007	0.007	0.005
Ni						
Total	4.000	4.000	4.000	4.000	4.000	4.000
Ideal Site Occupancy						
Si	1.825	1.849	1.874	1.900	1.885	1.873
Al iv	0.175	0.151	0.126	0.100	0.115	0.127
Fe ³ iv						
T site =	2.000	2.000	2.000	2.000	2.000	2.000
Al vi	0.026	0.045	0.027	0.054	0.037	0.065
Fe ³ vi	0.134	0.086	0.086	0.036	0.066	0.044
Ti	0.022	0.016	0.013	0.012	0.012	0.015
Cr	0.002	0.006	0.005	0.007	0.007	0.005
Ni						
Mg	0.793	0.803	0.862	0.872	0.844	0.813
Fe ²	0.023	0.046	0.007	0.020	0.034	0.058
Mn	0.004	0.003	0.003	0.002	0.002	0.003
M1 site =	1.004	1.003	1.003	1.002	1.002	1.003
Mg						
Fe ²	0.180	0.116	0.168	0.122	0.127	0.101
Mn						
Li						
K						
Ca	0.785	0.863	0.811	0.856	0.852	0.878
Na	0.031	0.017	0.018	0.020	0.019	0.018
M2 site =	0.996	0.997	0.997	0.998	0.998	0.997
Chemical Group	Quad	Quad	Quad	Quad	Quad	Quad
Calculated Name	ferrian augite	diopside	augite	augite	augite	diopside

WHITE HILL PYROXENE COMPOSITIONS & NAMES

Sample	OU 63914	OU 63914	OU 63918	OU 63918	OU 63918	OU 63918	OU 63917
	Core	Core	Core	Rim	Core	Rim	Rim
SiO2	51.47	51.14	52.08	51.38	51.72	51.84	51.13
Al2O3	2.93	2.51	2.24	1.91	2.48	1.92	2.55
TiO2	0.48	0.72	0.45	0.53	0.47	0.46	0.50
FeO*	9.66	12.13	9.76	12.58	8.81	10.75	10.75
MnO	0.24	0.23	0.26	0.40	0.24	0.35	0.27
MgO	15.47	15.00	15.34	14.02	15.45	15.35	15.11
CaO	19.88	18.78	19.09	18.79	20.60	19.56	19.62
Na2O	0.34	0.33	0.30	0.25	0.29	0.34	0.29
K2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr2O3	0.04	0.05	0.00	0.00	0.02	0.04	0.00
NiO	0.04	0.00	0.00	0.00	0.00	0.00	0.04
ZrO2							
V2O3							
Sc2O3							
Li2O							
Total	100.55	100.89	99.52	99.86	100.08	100.61	100.26
Recalculated							
Fe2O3	2.88	3.22	0.60	1.44	2.29	3.00	3.21
FeO	7.07	9.24	9.22	11.28	6.75	8.05	7.86
Total	100.84	101.21	99.58	100.00	100.31	100.91	100.58
Cations							
Si	1.895	1.892	1.941	1.931	1.911	1.915	1.896
Al	0.127	0.109	0.098	0.085	0.108	0.084	0.111
Ti	0.013	0.020	0.013	0.015	0.013	0.013	0.014
Fe3+	0.080	0.090	0.017	0.041	0.064	0.083	0.090
Fe2+	0.218	0.286	0.287	0.355	0.208	0.249	0.244
Mn	0.007	0.007	0.008	0.013	0.008	0.011	0.008
Mg	0.849	0.827	0.852	0.786	0.851	0.845	0.835
Ca	0.784	0.744	0.762	0.757	0.816	0.774	0.780
Na	0.024	0.024	0.022	0.018	0.021	0.024	0.021
K							
Cr	0.001	0.001			0.001	0.001	
Ni	0.001						0.001
Total	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Ideal Site Occupancy							
Si	1.895	1.892	1.941	1.931	1.911	1.915	1.896
Al iv	0.105	0.108	0.059	0.069	0.089	0.084	0.104
Fe3 iv						0.001	
T site =	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Al vi	0.022	0.001	0.039	0.016	0.019		0.007
Fe3 vi	0.080	0.090	0.017	0.041	0.064	0.082	0.090
Ti	0.013	0.020	0.013	0.015	0.013	0.013	0.014
Cr	0.001	0.001			0.001	0.001	
Ni	0.001						0.001
Mg	0.849	0.827	0.852	0.786	0.851	0.845	0.835
Fe2	0.034	0.061	0.079	0.143	0.052	0.058	0.053
Mn	0.007	0.007	0.008	0.013	0.008	0.011	0.008
M1 site =	1.007	1.007	1.008	1.013	1.008	1.011	1.008
Mg							
Fe2	0.184	0.225	0.208	0.212	0.156	0.190	0.191
Mn							
Li							
K							
Ca	0.784	0.744	0.762	0.757	0.816	0.774	0.780
Na	0.024	0.024	0.022	0.018	0.021	0.024	0.021
M2 site =	0.993	0.993	0.992	0.987	0.992	0.989	0.992
Chemical							
Group	Quad	Quad	Quad	Quad	Quad	Quad	Quad
Calcaluated							
Name	augite	augite	augite	augite	augite	augite	augite

Sample	OU 63917	OU 63917	OU 63915	OU 63915	OU 63915	OU 63924	OU 63920
	Core	Core	Rim	Core	Core	Core	Rim
SiO2	51.36	51.40	51.62	52.06	52.52	50.89	53.26
Al2O3	2.78	2.90	3.28	3.08	3.09	2.64	2.26
TiO2	0.57	0.50	0.49	0.49	0.50	0.71	0.59
FeO*	8.15	7.42	7.67	7.83	8.39	11.66	7.40
MnO	0.23	0.18	0.15	0.17	0.21	0.35	0.27
MgO	15.43	15.28	14.39	14.78	14.76	14.75	15.86
CaO	20.26	21.01	22.09	22.31	21.29	18.95	21.66
Na2O	0.28	0.21	0.24	0.25	0.26	0.23	0.23
K2O	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Cr2O3	0.16	0.13	0.00	0.03	0.00	0.00	0.03
NiO	0.05	0.00	0.00	0.00	0.03	0.00	
ZrO2							
V2O3							
Sc2O3							
Li2O							
Total	99.27	99.03	99.93	101.02	101.05	100.17	101.58
Recalculated							
Fe2O3	1.41	0.91	0.80	1.63	0.19	2.39	0.65
FeO	6.88	6.60	6.95	6.36	8.22	9.50	6.82
Total	99.41	99.12	100.01	101.18	101.07	100.41	101.64
Cations							
Si	1.911	1.915	1.912	1.906	1.926	1.897	1.934
Al	0.122	0.127	0.143	0.133	0.134	0.116	0.097
Ti	0.016	0.014	0.014	0.013	0.014	0.020	0.016
Fe3+	0.039	0.026	0.022	0.045	0.005	0.067	0.018
Fe2+	0.214	0.206	0.215	0.195	0.252	0.296	0.207
Mn	0.007	0.006	0.005	0.005	0.007	0.011	0.008
Mg	0.856	0.849	0.795	0.807	0.807	0.819	0.859
Ca	0.808	0.839	0.877	0.875	0.837	0.757	0.843
Na	0.020	0.015	0.017	0.018	0.018	0.017	0.016
K				0.001			
Cr	0.005	0.004		0.001			0.001
Ni	0.001				0.001		
Total	4.000	4.000	4.000	4.000	4.000	4.000	4.000
Ideal Site Occu							
Si	1.911	1.915	1.912	1.906	1.926	1.897	1.934
Al iv	0.089	0.085	0.088	0.094	0.074	0.103	0.066
Fe3 iv							
T site =	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Al vi	0.033	0.043	0.055	0.039	0.060	0.013	0.031
Fe3 vi	0.039	0.026	0.022	0.045	0.005	0.067	0.018
Ti	0.016	0.014	0.014	0.013	0.014	0.020	0.016
Cr	0.005	0.004		0.001			0.001
Ni	0.001				0.001		
Mg	0.856	0.849	0.795	0.807	0.807	0.819	0.859
Fe2	0.049	0.065	0.114	0.094	0.114	0.081	0.075
Mn	0.007	0.006	0.005	0.005	0.007	0.011	0.008
M1 site =	1.007	1.006	1.005	1.005	1.007	1.011	1.008
Mg							
Fe2	0.165	0.140	0.101	0.101	0.138	0.216	0.132
Mn							
Li							
K				0.001			
Ca	0.808	0.839	0.877	0.875	0.837	0.757	0.843
Na	0.020	0.015	0.017	0.018	0.018	0.017	0.016
M2 site =	0.993	0.994	0.995	0.995	0.993	0.989	0.992
Chemical							
Group	Quad	Quad	Quad	Quad	Quad	Quad	Quad
Calculated							
Name	augite	augite	diopside	diopside	augite	augite	augite

Sample	OU 63923	OU 63923	OU 63923	OU 63923	OU 63923
	Rim	Core	Rim	Rim	-
SiO2	48.74	51.21	48.38	46.98	49.67
Al2O3	5.51	2.59	4.14	5.65	4.12
TiO2	0.60	0.29	0.64	0.90	0.30
FeO*	10.68	11.54	12.08	12.08	8.56
MnO	0.22	0.38	0.24	0.25	0.13
MgO	14.38	15.70	14.74	13.99	15.44
CaO	21.43	18.92	19.76	19.10	21.38
Na2O	0.24	0.26	0.13	0.23	0.10
K2O	0.00	0.00	0.02	0.00	0.00
Cr2O3	0.04	0.00	0.00	0.00	0.24
NiO					
ZrO2					
V2O3					
Sc2O3					
Li2O					
Total	101.85	100.89	100.12	99.19	99.95
Recalculated					
Fe2O3	6.98	4.30	6.87	6.47	4.88
FeO	4.40	7.67	5.90	6.25	4.17
Total	102.55	101.32	100.81	99.84	100.44
Cations					
Si	1.777	1.886	1.801	1.766	1.834
Al	0.237	0.112	0.181	0.251	0.179
Ti	0.017	0.008	0.018	0.025	0.008
Fe3+	0.191	0.119	0.192	0.183	0.136
Fe2+	0.134	0.236	0.184	0.197	0.129
Mn	0.007	0.012	0.007	0.008	0.004
Mg	0.782	0.862	0.818	0.784	0.850
Ca	0.837	0.747	0.788	0.769	0.846
Na	0.017	0.019	0.010	0.017	0.007
K			0.001		
Cr	0.001				0.007
Ni					
Total	4.000	4.000	4.000	4.000	4.000
Ideal Site Occu					
Si	1.777	1.886	1.801	1.766	1.834
Al iv	0.223	0.112	0.181	0.234	0.166
Fe3 iv		0.002	0.018		
T site =	2.000	2.000	2.000	2.000	2.000
Al vi	0.014			0.017	0.013
Fe3 vi	0.191	0.117	0.174	0.183	0.136
Ti	0.017	0.008	0.018	0.025	0.008
Cr	0.001				0.007
Ni					
Mg	0.777	0.862	0.808	0.775	0.835
Fe2		0.013			
Mn		0.012			
M1 site =	1.000	1.012	1.000	1.000	1.000
Mg	0.005		0.010	0.009	0.014
Fe2	0.134	0.223	0.184	0.197	0.129
Mn	0.007		0.007	0.008	0.004
Li					
K			0.001		
Ca	0.837	0.747	0.788	0.769	0.846
Na	0.017	0.019	0.010	0.017	0.007
M2 site =	1.000	0.988	1.000	1.000	1.000
Chemical					
Group	Quad	Quad	Quad	Quad	Quad
Calculated					
Name	ferrian augite	ferrian augite	ferrian augite	ferrian aluminum-bearing augite	ferrian augite

Sample	OU 63923	OU 63923
	-	Core
SiO2	48.36	47.00
Al2O3	5.57	6.55
TiO2	0.66	0.68
FeO*	8.48	8.69
MnO	0.11	0.08
MgO	14.54	13.82
CaO	21.76	21.91
Na2O	0.11	0.10
K2O	0.00	0.00
Cr2O3	0.07	0.17
NiO		
ZrO2		
V2O3		
Sc2O3		
Li2O		
Total	99.66	99.00
Recalculated		
Fe2O3	4.97	5.73
FeO	4.01	3.54
Total	100.16	99.58
Cations		
Si	1.793	1.757
Al	0.243	0.289
Ti	0.018	0.019
Fe3+	0.139	0.161
Fe2+	0.124	0.111
Mn	0.004	0.002
Mg	0.804	0.770
Ca	0.865	0.878
Na	0.008	0.008
K		
Cr	0.002	0.005
Ni		
Total	4.000	4.000
Ideal Site Occ		
Si	1.793	1.757
Al iv	0.207	0.243
Fe3 iv		
T site =	2.000	2.000
Al vi	0.037	0.046
Fe3 vi	0.139	0.161
Ti	0.018	0.019
Cr	0.002	0.005
Ni		
Mg	0.804	0.769
Fe2		
Mn		
M1 site =	1.000	1.000
Mg		0.002
Fe2	0.124	0.111
Mn	0.003	0.002
Li		
K		
Ca	0.865	0.878
Na	0.008	0.008
M2 site =	1.000	1.000
Chemical Group	Quad	Quad
Calculated Name	ferrian augite	ferrian aluminum-bearing diopside

Appendix D.
NORMATIVE TABLES

Takitimu Group Volcanics

Rockname: BASALTIC-ANDESITE											
Locality: OU 63926											
primary (y/n)		Batch.CIPW=control,option,b									
cancrinite calcite											
n	y	Norm									
SiO2	53.92	H2O	2.74	Q	na		ca				
TiO2	1.39	CO2		C	ka		mt	6.19			
Al2O3	14.56	NiO		Z	di	15.55	cm				
Fe2O3	4.27	BaO		or	6.74	wo	7.96	il	2.64		
FeO	6.40	SrO		ab	50.84	en	4.63	hm			
MnO	0.19	F		an	2.83	fs	2.96	tn			
MgO	3.95	Cl		lc		wo		pf			
CaO	4.81	SO3		ne	6.70	hy		ru			
Na2O	7.47	Cr2O3		kp		en		ap	0.70		
K2O	1.14	ZrO2		hl		fs		fr			
P2O5	0.30	S		th		ol	6.22	pr			
Total		101.14		nc		fo	3.65	cc			
				ac		fa	2.57	H2	2.74		
		Total 101.14									

Rockname: BASALTIC-ANDESITE									
Locality: OU 63927									
primary (y/n)		Batch.CIPW=control,option,b							
cancrinite calcite									
n	y	Norm							
SiO2	52.96	H2O	2.21	Q	3.48	na		cs	
TiO2	0.50	CO2		C		ka		mt	4.26
Al2O3	15.81	NiO		Z		di	15.32	em	
Fe2O3	2.94	BaO		or	2.19	wo	8.02	il	0.95
FeO	4.41	SrO		ab	26.57	en	5.74	hm	
MnO	0.14	F		an	27.95	fs	1.56	tn	
MgO	7.55	Cl		lc		wo		pf	
CaO	9.69	SO3		ne		hy	16.60	ru	
Na2O	3.14	Cr2O3		kp		en	13.06	ap	0.32
K2O	0.37	ZrO2		hl		fs	3.54	fr	
P2O5	0.14	S		th		ol		pr	
Total		99.86		nc		fo		cc	
				ac		fa		H2O	2.21
								Total	99.86

Rockname: BASALTIC-ANDESITE (PILLOW)												
Locality: OU 63928												
primary (y/n)		Batch.CIPW=control,option,b										
cancrinite calcite												
n	y	Norm										
SiO2	53.03	H2O	3.86	Q	5.14	na		ca				
TiO2	1.29	CO2		C		ka		mt	6.25			
Al2O3	14.64	NiO		Z		di	9.89	cm				
Fe2O3	4.31	BaO		or	3.55	wo	5.05	il		2.45		
FeO	6.47	SrO		ab	39.18	en	2.83	hm				
MnO	0.21	F		an	17.39	fs	2.01	tn				
MgO	3.72	Cl		lc		wo		pf				
CaO	6.35	SO3		ne		hy	11.00	ru				
Na2O	4.63	Cr2O3		kp		en	6.43	ap	0.72			
K2O	0.60	ZrO2		hl		fs	4.56	fr				
P2O5	0.31	S		th		ol		pr				
Total			99.42	nc		fo		cc				
				ac		fa		H2O	3.86			
			Total									99.42

Rockname: BASALTIC-ANDESITE									
Locality: OU 63931									
primary (y/n) Batch.CIPW=control,option,b									
cancrinite calcite									
n	y	Norm							
SiO2	55.81	H2O	1.98	Q	na	ca			
TiO2	0.62	CO2		C	ka	mt	3.98		
Al2O3	17.22	NiO		Z	di	11.55	cm		
Fe2O3	2.75	BaO		or	12.47	wo	6.04	il	1.18
FeO	4.12	SrO		ab	42.63	en	4.31	hm	
MnO	0.14	F		an	17.19	fs	1.20	tn	
MgO	6.54	Cl		lc		wo		pf	
CaO	6.67	SO3		ne	0.97	hy		ru	
Na2O	5.25	Cr2O3		kp		en		ap	0.51
K2O	2.11	ZrO2		hl		fs		fr	
P2O5	0.22	S		th		ol	10.97	pr	
Total		103.43		nc		fo	8.40	ce	
				ac		fa	2.58	H2	1.98
				Total 103.43					

NORMATIVE TABLES

Takitimu Group Volcaniclastics

Rockname:ARENITE											
Locality:OU 63937											
primary (y/n) Batch.CIPW=control,option,b											
cancrinite calcite											
n	y	Norm									
SiO2	53.58	H2O	4.70	Q	na	ca					
TiO2	0.75	CO2		C	ka	mt	4.55				
Al2O3	17.75	NiO		Z	di	cm					
Fe2O3	3.14	BaO		or	7.74	wo	2.17	il	1.42		
FeO	4.71	SrO		ab	48.40	en	1.31	hm			
MnO	0.16	F		an	18.89	fs	0.74	tn			
MgO	3.63	Cl		lc		wo		pf			
CaO	5.08	SO3		ne		hy	5.78	ru			
Na2O	5.72	Cr2O3		kp		en	3.70	ap	0.39		
K2O	1.31	ZrO2		hl		fs	2.09	fr			
P2O5	0.17	S		th		ol	4.59	pr			
Total		100.70		nc		fo	2.83	cc			
				ac		fa	1.76	H2	4.70		
				Total							
				100.70							

Rockname:LUTITE											
Locality:OU 63940											
primary (y/n) Batch.CIPW=control,option,b											
cancrinite calcite											
n	y	Norm									
SiO2	49.47	H2O	2.78	Q	na	ca					
TiO2	1.63	CO2		C	ka	mt	5.52				
Al2O3	17.39	NiO		Z	di	cm					
Fe2O3	3.81	BaO		or	8.21	wo	5.63	il	3.10		
FeO	5.71	SrO		ab	27.16	en	3.81	hm			
MnO	0.17	F		an	28.94	fs	1.39	tn			
MgO	5.46	Cl		lc		wo		pf			
CaO	8.80	SO3		ne		hy	12.18	ru			
Na2O	3.21	Cr2O3		kp		en	8.93	ap	0.44		
K2O	1.39	ZrO2		hl		fs	3.26	fr			
P2O5	0.19	S		th		ol	0.85	pr			
Total		100.01		nc		fo	0.61	cc			
				ac		fa	0.24	H2	2.78		
				Total							
				100.01							

Rockname:ARENITE											
Locality:OU 63944											
primary (y/n) Batch.CIPW=control,option,b											
cancrinite calcite											
n	y	Norm									
SiO2	49.46	H2O	6.4900628	Q	na	ca					
TiO2	1.06	CO2		C	ka	mt	5.39				
Al2O3	15.90	NiO		Z	di	cm					
Fe2O3	3.72	BaO		or	6.26	wo	6.24	il	2.01		
FeO	5.58	SrO		ab	40.35	en	3.88	hm			
MnO	0.18	F		an	16.42	fs	1.99	tn			
MgO	4.52	Cl		lc		wo		pf			
CaO	6.64	SO3		ne	2.48	hy		ru			
Na2O	5.31	Cr2O3		kp		en		ap	0.56		
K2O	1.06	ZrO2		hl		fs		fr			
P2O5	0.24	S		th		ol	8.08	pr			
Total		100.16		nc		fo	5.17	cc			
				ac		fa	2.91	H2	6.49		
				Total							
				100.16							

Rockname:ARENITE											
Locality:OU 63947											
primary (y/n) Batch.CIPW=control,option,b											
cancrinite calcite											
n	y	Norm									
SiO2	52.18	H2O	4.15	Q	4.07	na	ca				
TiO2	0.89	CO2		C		ka	mt	5.66			
Al2O3	15.84	NiO		Z		di	cm				
Fe2O3	3.90	BaO		or	4.79	wo	6.02	il	1.69		
FeO	5.86	SrO		ab	31.82	en	3.64	hm			
MnO	0.18	F		an	23.95	fs	2.06	tn			
MgO	4.54	Cl		lc		wo		pf			
CaO	7.97	SO3		ne		hy	12.01	ru			
Na2O	3.76	Cr2O3		kp		en	7.67	ap	0.42		
K2O	0.81	ZrO2		hl		fs	4.34	fr			
P2O5	0.18	S		th		ol		pr			
Total		100.26		nc		fo		cc			
				ac		fa		H2	4.15		
				Total							
				100.26							

Rockname:ARENITE											
Locality:OU 63954											
primary (y/n) Batch.CIPW=control,option,b											
cancrinite calcite											
n	y	Norm									
SiO2	53.43	H2O	6.31	Q	10.82	na	ca				
TiO2	1.08	CO2		C		ka	mt	5.16			
Al2O3	14.88	NiO		Z		di	cm				
Fe2O3	3.554	BaO		or	4.37	wo	5.70	il	2.05		
FeO	5.332	SrO		ab	27.16	en	3.38	hm			
MnO	0.16	F		an	24.01	fs	2.04	tn			
MgO	3.58	Cl		lc		wo		pf			
CaO	8.08	SO3		ne		hy	8.87	ru			
Na2O	3.21	Cr2O3		kp		en	5.54	ap	0.86		
K2O	0.74	ZrO2		hl		fs	3.33	fr			
P2O5	0.37	S		th		ol		pr			
Total		100.73		nc		fo		cc			
				ac		fa		H2	6.31		
				Total							
				100.73							

Rockname:ARENITE											
Locality:OU 63955											
primary (y/n) Batch.CIPW=control,option,b											
cancrinite calcite											
n	y	Norm									
SiO2	51.38	H2O	2.62	Q		na	ca				
TiO2	0.96	CO2		C		ka	mt	5.47			
Al2O3	16.85	NiO		Z		di	cm				
Fe2O3	3.78	BaO		or	10.64	wo	8.13	il	1.82		
FeO	5.66	SrO		ab	36.13	en	4.68	hm			
MnO	0.14	F		an	18.84	fs	3.08	tn			
MgO	3.63	Cl		lc		wo		pf			
CaO	7.96	SO3		ne	2.70	hy		ru			
Na2O	4.86	Cr2O3		kp		en		ap	0.42		
K2O	1.80	ZrO2		hl		fs		fr			
P2O5	0.18	S		th		ol	5.28	pr			
Total		99.82		nc		fo	3.06	cc			
				ac		fa	2.22	H2	2.62		
				Total							
				99.82							

Rockname:ARENITE											
Locality:OU 63956											
primary (y/n)				Batch.CIPW=control,option,b							
cancrinite calcite											
n		y		Norm							
SiO2	51.69	H2O	5.21	Q	2.25	na		ca			
TiO2	0.89	CO2		C		ka		mt		4.86	
Al2O3	15.91	NiO		Z		di	13.38	cm			
Fe2O3	3.36	BaO		or	7.09	wo	6.89	il		1.69	
FeO	5.03	SrO		ab	33.76	en	4.28	hm			
MnO	0.17	F		an	21.96	fs	2.21	tn			
MgO	4.14	Cl		lc		wo		pf			
CaO	8.03	SO3		ne		hy	9.14	ru			
Na2O	3.99	Cr2O3		kp		en	6.03	ap		0.49	
K2O	1.20	ZrO2		hl		fs	3.11	fr			
P2O5	0.21	S		th		ol		pr			
Total			99.83	nc		fo		ce			
				ac		fa		H2O	5.21		
										Total	99.83

NORMATIVE TABLES

White Hill Intrusives

Rockname: BASALT														
Locality: OU 63915														
primary (y/n) Batch.CIPW=control,option,b														
cancrinite calcite														
n	y	Norm												
SiO2	52.08	H2O	3.64	Q	0.65	na		ca						
TiO2	0.95	CO2		C		ka		mt	5.04					
Al2O3	16.37	NiO		Z		di	11.76	cm						
Fe2O3	3.48	BaO		or	5.91	wo	6.05	il	1.80					
FeO	5.22	SrO		ab	38.92	en	3.73	hm						
MnO	0.16	F		an	21.06	fs	1.98	tn						
MgO	4.12	Cl		lc		wo		pf						
CaO	7.55	SO3		ne		hy	10.00	ru						
Na2O	4.60	Cr2O3		kp		en	6.53	ap	0.67					
K2O	1.00	ZrO2		hl		fs	3.46	fr						
P2O5	0.29	S		th		ol		pr						
Total		99.46		nc		fo		cc						
				ac		fa		H2	3.64					
				Total										
				99.46										

Rockname: GABBRO														
Locality: OU 63916														
primary (y/n) Batch.CIPW=control,option,b														
cancrinite calcite														
n	y	Norm												
SiO2	51.83	H2O	3.81	Q		na		ca						
TiO2	0.90	CO2		C		ka		mt	4.90					
Al2O3	16.16	NiO		Z		di	19.76	cm						
Fe2O3	3.38	BaO		or	7.56	wo	10.18	il	1.71					
FeO	5.07	SrO		ab	37.73	en	6.32	hm						
MnO	0.17	F		an	14.14	fs	3.26	tn						
MgO	4.17	Cl		lc		wo		pf						
CaO	8.07	SO3		ne	6.29	hy		ru						
Na2O	5.83	Cr2O3		kp		en		ap	0.53					
K2O	1.28	ZrO2		hl		fs		fr						
P2O5	0.23	S		th		ol	4.46	pr						
Total		100.91		nc		fo	2.85	cc						
				ac		fa	1.62	H2	3.81					
				Total										
				100.91										

Rockname: GABBRO														
Locality: OU 63917														
primary (y/n) Batch.CIPW=control,option,b														
cancrinite calcite														
n	y	Norm												
SiO2	52.09	H2O	1.69	Q	4.67	na		ca						
TiO2	0.87	CO2		C		ka		mt	5.72					
Al2O3	14.56	NiO		Z		di	19.30	cm						
Fe2O3	3.94	BaO		or	4.73	wo	10.01	il	1.65					
FeO	5.92	SrO		ab	22.51	en	6.61	hm						
MnO	0.22	F		an	25.43	fs	2.67	tn						
MgO	6.53	Cl		lc		wo		pf						
CaO	10.18	SO3		ne		hy	13.55	ru						
Na2O	2.66	Cr2O3		kp		en	9.65	ap	0.39					
K2O	0.80	ZrO2		hl		fs	3.90	fr						
P2O5	0.17	S		th		ol		pr						
Total		99.63		nc		fo		cc						
				ac		fa		H2	1.69					
				Total										
				99.63										

Rockname: GABBRO														
Locality: OU 63918														
primary (y/n) Batch.CIPW=control,option,b														
cancrinite calcite														
n	y	Norm												
SiO2	52.01	H2O	2.74	Q	0.82	na		ca						
TiO2	0.92	CO2		C		ka		mt	5.39					
Al2O3	16.44	NiO		Z		di	13.53	cm						
Fe2O3	3.72	BaO		or	5.97	wo	6.98	il	1.75					
FeO	5.58	SrO		ab	34.19	en	4.38	hm						
MnO	0.18	F		an	23.74	fs	2.17	tn						
MgO	4.85	Cl		lc		wo		pf						
CaO	8.47	SO3		ne		hy	11.52	ru						
Na2O	4.04	Cr2O3		kp		en	7.70	ap	0.56					
K2O	1.01	ZrO2		hl		fs	3.82	fr						
P2O5	0.24	S		th		ol		pr						
Total		100.20		nc		fo		cc						
				ac		fa		H2	2.74					
				Total										
				100.20										

Rockname: GABBRO														
Locality: OU 63919														
primary (y/n) Batch.CIPW=control,option,b														
cancrinite calcite														
n	y	Norm												
SiO2	48.54	H2O	3.06	Q		na		ca						
TiO2	0.95	CO2		C		ka		mt	5.11					
Al2O3	18.04	NiO		Z		di	19.96	cm						
Fe2O3	3.52	BaO		or	8.81	wo	10.30	il	1.80					
FeO	5.29	SrO		ab	23.75	en	6.48	hm						
MnO	0.15	F		an	20.09	fs	3.19	tn						
MgO	4.49	Cl		lc		wo		pf						
CaO	9.43	SO3		ne	12.39	hy		ru						
Na2O	5.51	Cr2O3		kp		en		ap	0.72					
K2O	1.49	ZrO2		hl		fs		fr						
P2O5	0.31	S		th		ol	5.09	pr						
Total		100.78		nc		fo	3.30	cc						
				ac		fa	1.79	H2	3.06					
				Total										
				100.78										

Rockname: GABBRO														
Locality: OU 63920														
primary (y/n)					Batch.CIPW=control,option,b									
cancrinite calcite														
n	y	Norm												
SiO2	48.37	H2O	2.85	Q		na		ca						
TiO2	1.06	CO2		C		ka		mt	5.54					
Al2O3	17.28	NiO		Z		di	22.62	cm						
Fe2O3	3.82	BaO		or	9.81	wo	11.66	il	2.01					
FeO	5.74	SrO		ab	21.51	en	7.28	hm						
MnO	0.16	F		an	15.58	fs	3.68	tn						
MgO	4.71	Cl		lc		wo		pf						
CaO	9.22	SO3		nc	15.57	hy		ru						
Na2O	5.94	Cr2O3		kp		en		ap	0.79					
K2O	1.66	ZrO2		hl		fs		fr						
P2O5	0.34	S		th		ol	4.85	pr						
Total		101.16		nc		fo	3.12	cc						
				ac		fa	1.73	H2O	2.85					
Total													101.15	

NORMATIVE TABLES

Rockname: GABBRO									
Locality: OU 63923									
primary (y/n)		Batch.CIPW=control,option,b							
cancrinite calcite									
n	y	Norm							
SiO2	49.15	H2O	2.42	Q	na	ca			
TiO2	0.62	CO2		C	ka	mt	5.01		
Al2O3	18.11	NiO		Z	di	17.94	em		
Fe2O3	3.45	BaO		or	5.14	wo	9.30	il	1.18
FeO	5.18	SrO		ab	27.70	en	6.13	hm	
MnO	0.15	F		an	24.94	fs	2.51	tn	
MgO	5.81	Cl		lc		wo		pf	
CaO	9.78	SO3		ne	7.36	hy		ru	
Na2O	4.88	Cr2O3		kp		en		ap	0.46
K2O	0.87	ZrO2		hl		fs		fr	
P2O5	0.20	S		th		ol	8.48	pr	
Total		100.62		nc		fo	5.84	ce	
				ac		fa	2.63	H2	2.42
				Total					
				100.62					

Appendix E.
MODAL ANALYSES

For each thin section >400 points were counted. The symbols used in the tables are as follows:

- Qm- monocrystalline quartz
- Qp- pollycrystalline quartz
- Plag- plagioclase
- Lsv- silicic volcanic lithics
- Li-mv- intermediate to mafic volcanic lithics
- Lplut- plutonic lithics
- Lsed- sedimentary lithics

Takitimu Group Arenites

POINT COUNT DATA FOR TAKITIMU GROUP ARENITES

	OU 63937		OU 63943		OU 63941		OU 63946		OU 63939		OU 63940	
	No. Counted	%	No. Counted	%	No. Counted	%	No. Counted	%	No. Counted	%	No. Counted	%
Qm	0	0	0	0	11	2.69	0	0	7	1.59	4	0.92
Qp	0	0	0	0	0	0	0	0	0	0	0	0
Plag	89	19.43	132	32.75	56	13.69	83	19.44	52	11.82	94	21.66
Lsv	32	6.99	0	0	0	0	5	1.17	1	0.23	0	0
Li-mv	113	24.67	47	11.66	22	5.38	85	19.91	98	22.27	72	16.59
Lplut	0	0	0	0	0	0	0	0	2	0.45	0	0
Lsed	0	0	0	0	11	2.69	0	0	35	7.95	6	1.38
Epidote	0	0	0	0	0	0	0	0	0	0	0	0
Hornblende	0	0	1	0.25	0	0	0	0	0	0	0	0
Pyroxene	5	1.09	49	12.16	48	11.74	8	1.87	29	6.59	28	6.45
Chlorite-vermiculite	0	0	0	0	0	0	0	0	2	0.45	5	1.15
Opauques	31	6.77	19	4.71	80	19.56	69	16.16	31	7.05	56	12.90
Zeolite	60	13.10	24	5.96	15	3.67	42	9.84	49	11.14	40	9.22
Chlorite/matrix	36	7.86	26	6.45	30	7.33	43	10.07	33	7.50	48	11.06
Chlorite/alt	21	4.69	19	4.71	20	4.89	20	4.68	16	3.64	29	6.68
Matrix	13	2.84	24	5.96	105	25.67	10	2.34	24	5.45	6	1.38
Calcite	0	0	0	0	2	0.49	0	0	28	6.36	3	0.69
Glass	30	6.65	37	9.18	4	0.98	0	0	0	0	0	0
Void	1	0.22	2	0.50	0	0	10	2.34	1	0.23	1	0.23
Limonite	27	5.90	23	5.71	5	1.22	52	12.18	26	5.91	21	4.84
Celadonite	0	0	0	0	0	0	0	0	2	0.45	12	2.76
Iddingsite	0	0	0	0	0	0	0	0	4	0.91	9	2.07
TOTAL	468	100	403	100	409	100	427	100	440	100	434	100
Quartz	0	0	0	0	11	2.69	0	0	7	1.59	4	0.92
Feldspar	38	8.12	74	18.36	56	13.69	83	19.44	52	11.82	94	21.66
Lithic	62	13.25	26	6.45	30	7.33	43	10.07	33	7.50	48	11.06
Total (Q+F+L)	61.09		44.42		24.45		40.52		44.32		40.55	
Lvole/Ltotal	1.00		1.00		0.67		1.00		0.73		0.92	
Li-mv/(Lsv+Li-mv)	0.78		1.00		1.00		0.94		0.99		1.00	

	OU 63944		OU 63954		OU 63942		OU 63945		OU 63938	
	No. Counted	%	No. Counted	%	No. Counted	%	No. Counted	%	No. Counted	%
Qm	11	2.66	22	5.06	19	4.53	3	0.74	4	0.89
Qp	0	0	0	0	4	0.95	0	0	0	0
Plag	48	11.59	57	13.10	52	12.41	67	16.50	94	20.89
Lsv	2	0.48	0	0	0	0	0	0	0	0
Li-mv	73	17.63	52	11.95	58	13.84	89	21.92	104	23.11
Lplut	0	0	0	0	0	0	0	0	0	0
Lsed	37	8.94	25	5.75	12	2.86	24	5.91	13	2.89
Epidote	3	0.72	2	0.46	0	0	0	0	0	0
Hornblende	0	0	0	0	0	0	0	0	0	0
Pyroxene	26	6.28	27	6.21	24	5.73	37	9.11	20	4.44
Chlorite-vermiculite	4	0.97	6	1.38	14	3.34	4	0.99	38	8.44
Opauques	37	8.94	36	8.28	27	6.44	37	9.11	40	8.89
Zeolite	45	10.87	84	19.31	61	14.56	53	13.05	37	8.22
Chlorite/matrix	24	5.80	1	0.23	29	6.92	7	1.72	21	4.67
Chlorite/alt	10	2.42	4	0.92	14	3.34	8	1.97	19	4.22
Matrix	65	15.70	32	7.36	51	12.17	32	7.88	10	2.22
Calcite	2	0.48	0	0	0	0	0	0	0	0
Glass	3	0.72	4	0.92	0	0	0	0	0	0
Void	2	0.48	10	2.30	0	0	1	0.25	12	2.67
Limonite	22	5.31	60	13.79	54	12.89	43	10.59	38	8.44
Celadonite	0	0	13	2.99	0	0	1	0.25	0	0
Iddingsite	0	0	0	0.00	0	0	0	0	0	0
TOTAL	414	100	435	100	419	100	406	100	450	100
Quartz	6	1.45	14	3.22	16	3.82	2	0.49	2	0.44
Feldspar	28	6.76	37	8.51	36	8.59	37	9.11	44	9.78
Lithic	65	15.70	49	11.27	48	11.46	62	15.28	54	12.00
Total (Q+F+L)	41.30		35.86		34.61		45.07		47.78	
Lvole/Ltotal	0.67		0.68		0.63		0.79		0.89	
Li-mv/(Lsv+Li-mv)	0.97		1.00		1.00		1.00		1.00	

Barretts Formation Sandstones

POINT COUNT DATA FOR BARRETS SANDSTONES

	OU 63950		OU 63951	
	No. Counted	%	No. Counted	%
Qm	72	13.69	54	12.44
Qp	22	4.18	10	2.30
Plag	31	5.89	59	13.59
K-spar	55	10.46	17	3.92
Lsv	2	0.38	0	0.00
Li-mv	26	4.94	15	3.46
Lplut	1	0.19	0	0.00
Lscd	16	3.04	23	5.30
Epidote	13	2.47	5	1.15
Pyroxene	0	0	2	0.46
Muscovite	6	1.14	2	0.46
Biotite	41	7.79	25	5.76
Opaques	102	19.39	86	19.82
Titanite	28	5.32	0	0
Zeolite	4	0.76	3	0.69
Chlorite/matrix	6	1.14	8	1.84
Chlorite/alt	45	8.56	3	0.69
Matrix	5	0.95	40	9.22
Void	0	0	10	2.30
Limonite	51	9.70	68	15.67
Celadonite	0	0	2	0.46
Iddingsite	0	0	2	0.46
TOTAL	526	100	434	100
Quartz		42		36
Feldspar		38		43
Lithic		20		21
Total (Q+F+L)		42.78		41.01
Lvolc/Ltotal		0.62		0.39
Li-mv/(Lsv+Li-mv)		0.93		1.00

Appendix F.

OPTICAL DISCRIPTIONS OF METAMORPHIC MINERALS

All these metamorphic minerals are colourless in thin-section. Some identifications were confirmed using X-ray diffraction techniques in combination with their optical properties.

Stilbite

Stilbite is one of the platy zeolites and hence often shows a single good cleavage may (or may not) show complex interpenetrative twinning. The birefringence may be slightly higher (0.008-0.014) than some of the other zeolites such as heulandite. Stilbite has a low 2V, is optically -ve and, is invariably length slow and has the optic axial plane (O.A.P.) parallel to the cleavage.

Heulandite

Heulandite is the another platy zeolite which has a single perfect cleavage. It does not however show complex intrapenetrative twinning. Low order birefringence (0.002-0.008) along with a small 2V, a +ve optic sign and an O.A.P. perpendicular to the cleavage. However, heulandite may be length fast or length slow.

Laumontite

Laumontite may show two cleavages and has an oblique extinction which bisects the two cleavages. A laumontite crystal is length slow when looking at a single cleavage. Birefringence (0.010-0.015) in laumontite is similar to stilbite and distinctly greater than heulandite. This zeolite, has a small 2V, is optically -ve and has the O.A.P. parallel to the cleavage.

Thomsonite

Thomsonite is a fibrous zeolite and is characterised in these rocks by botryoidal radiating spherulites which tend to be brownish in colour. Crystals of thomsonite may be length slow or length fast, and often show both length slow and length fast properties in crystals that are side by side. Thomsonite shows parallel extinction and low birefringence (0.006-0.016). It has two cleavages at 90° to each other, is optically +ve and has the O.A.P. perpendicular to the cleavage.

Gonnardite

Gonnardite often occurs in association with thomsonite. Thomsonite has been observed in overlapping relationships with gonnardite. Gonnardite has very low birefringence (0.001) and is almost isotropic. In one sample, gonnardite forms around the rims of vesicles with thomsonite forming in the centre. Gonnardite is length fast

has a fibrous habit.

Mordenite

Mordenite was discovered in one sample (OU 63927) using the X-ray diffraction technique on a sample obtained from veining within the rock (Appendix G).

Analcime

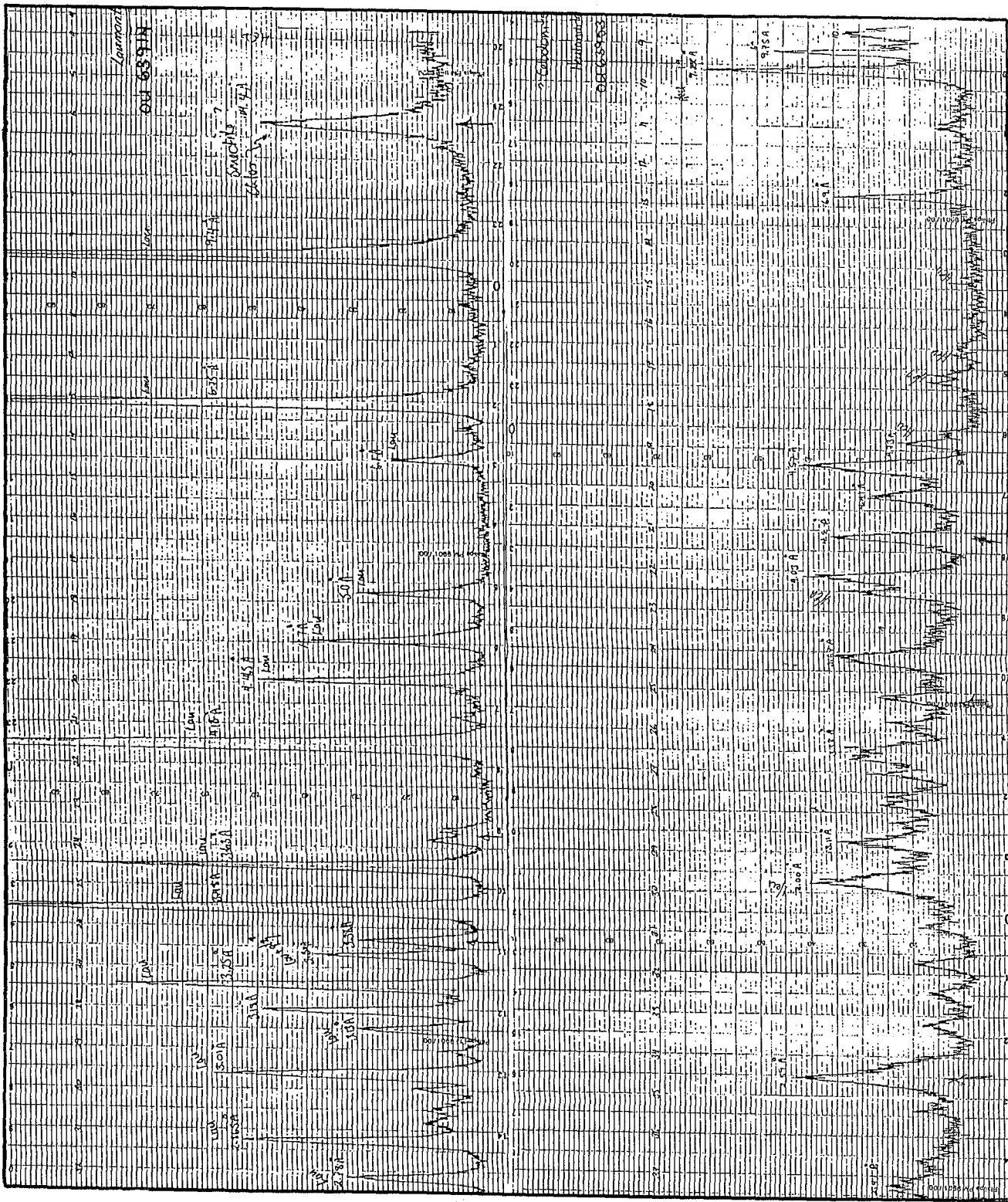
Analcime occurs within the rocks both as primary minerals (in volcanic lithologies) and authigenically. Analcime has a very poor cleavage and is isotropic (0.002).

Prehnite

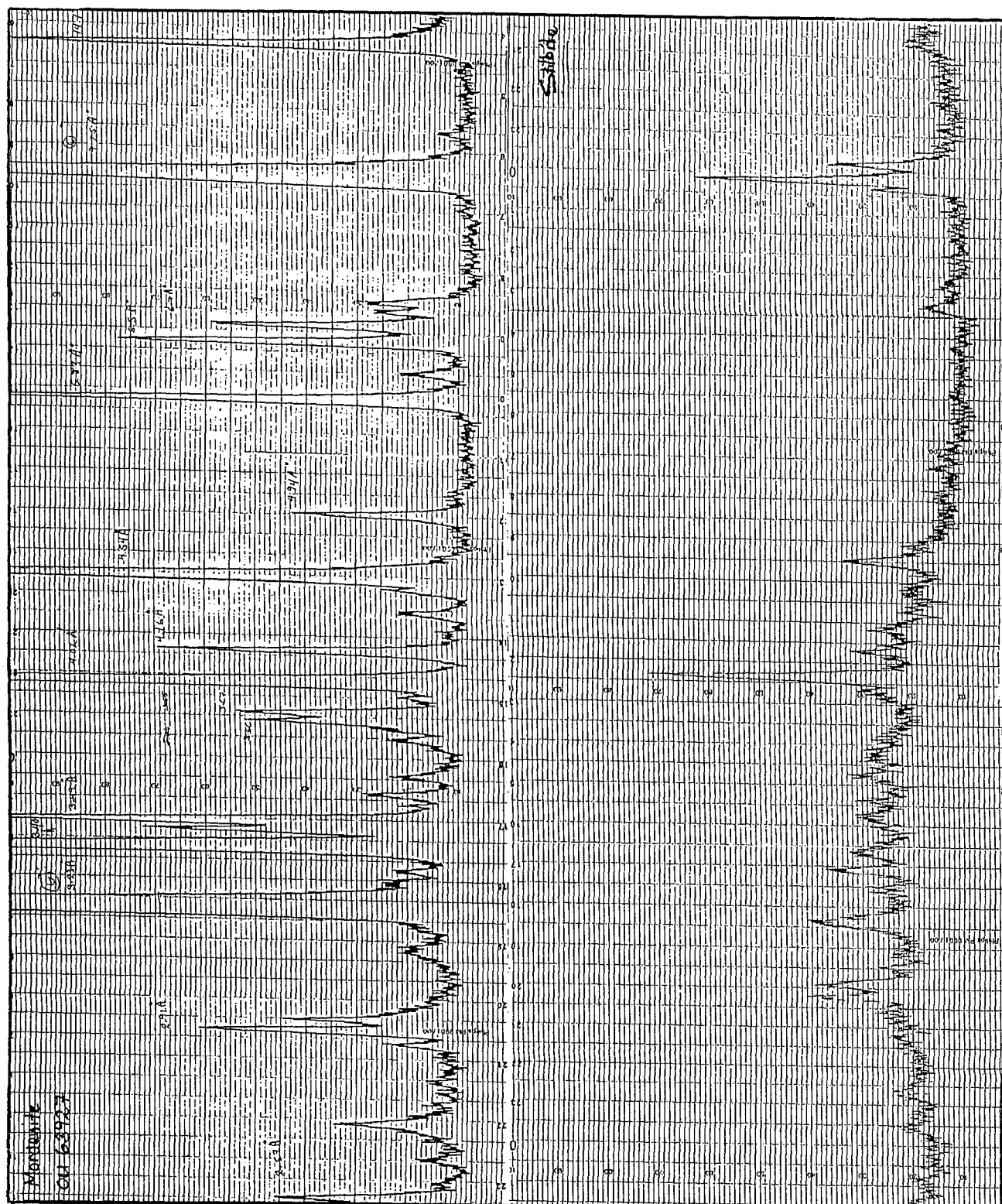
Prehnite is biaxial +ve and has moderate to high birefringence (0.021-0.035). It may show a distinct cleavage, has straight extinction and is length fast.

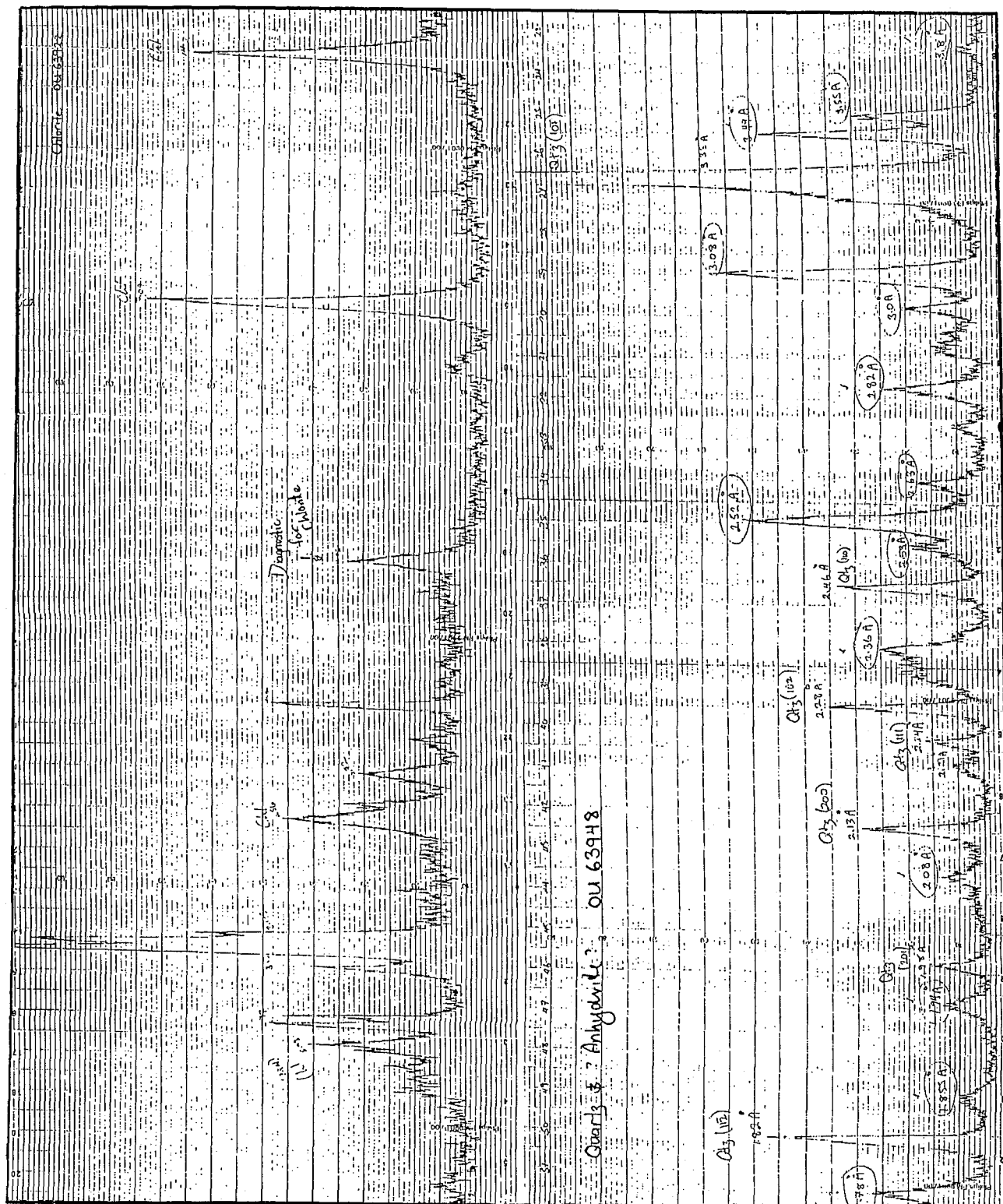
Appendix G.

XRD ANALYSES



XRD ANALYSES





FOSSIL RECORD FORM

PLEASE TYPE OR PRINT CLEARLY

Circle appropriate options

Initials of master-file curator: _____

D44 /f 296
NZMS260 Sheet serial number recolln.If collection from Cutting
drill-hole, state: Core depth m

GRID REFERENCE (NZ Map Grid):

Use only 3 digits unless from
1:25000 (or larger scale) source 1 986 162 760
map date easting northingDATE OF COLLECTION: - 5 1992
day month year

COLLECTOR(s): S. MACCULLOCH, M. MOSS

LOCALITY: On the right side of the road going clockwise
around Nugget Hill - to the east of Nugget
Hill.

LITHOSTRATIGRAPHIC NAME: MACLEAN PEAKS FNN, TAKITIMU GROUP.

FOSSILS IN PLACE?: ☒ Yes Almost No Unknown

SENT TO (Macrofauna)-

or HELD BY: (Microfauna)-

(Microflora)-

UNIVERSITY OF OTAGO

Other (specify) -

person

laboratory

OR NOT COLLECTED, but fossils seen (specify fossils):

SIGNIFICANCE OF SAMPLE, REMARKS:

Inferred stage PERMIAN Known stage limits Previous samples nearby /f /f

STRATIGRAPHIC
RELATIONSHIPS:

below

above

/f

below

above

/f

m below/above : top/base of rock unit

m below/above : top/base of rock unit

COLUMN or MAP, see:

steep dip W N E Vert. ☒ Normal ☐ Overturned
S strike (true)PREDOMINANT
GRAIN SIZES:☒ pri. ☐ sec.GRAIN-SIZE
COMPARATOR USED?Yes ☒ No

STRATIFICATION

(a) Bed thickness:

(b) Internal features

B boulder
C cobble
P pebble1 granule
2 very coarse sand
3 coarse sand4 medium sand
5 fine sand
6 very fine sand
8 clay7 silt
9 mud1 non-bedded
2 > 120 cm
3 60-120 cm
4 5-60 cm
5 1-5 cm
6 < 1 cm (laminated)G graded
S slump-folded
X cross bedded

WEATHERING:

☒ 1

HARDNESS:

☒ 4

CARBONATE:

☒ 1

COLOUR:

☒ D5Wet ☒ Dry1 none or slight
2 moderate
3 intense1 unconsolidated
2 moderately soft
3 moderately hard
4 hard1 non-calcareous
2 calcareous
3 limestoneL light
M medium
D dark1 white
2 grey
3 black4 red
5 brown
6 yellow7 green
8 blue
9 purple

ADDITIONAL FEATURES (Feature present, one letter; abundant, two letters): R

C carbonaceous
G glauconiticM micaceous
F phosphaticP pyritic
T tuffaceousZ sulphurous
B bentoniticS shelly
U burrowedO concretionary
R rock fragmentsQ highly quartzose
X feldspathic

INFERRED ENVIRONMENT Marine/Non-Marine or specify: MARINE

NATURE OF ROCK UNIT:

Include any characteristic
not already mentioned

CORRESPONDENCE, and CROSS-REFERENCES to other files:

S. MACCULLOCH BSc (Hons) Thesis 1992.
Nugget Hill

STAGE

ADOPTED:

BY:

Geologist, from all available data

DATE

COLLECTOR'S

FIELD NO.: STM 21.0

MANDATORY DATA for registration of form

STRATIGRAPHY

SEDIMENTARY FEATURES

FOSSIL RECORD NUMBER: D44 / f 296.

GROUP: Brachiopoda

IDENTIFIER: —

DATE: 1992

STAGE: COMMENT on STAGE DETERMINATION:

LAB. NUMBER: COMMENT on COLLECTION:

FORMAL TAXONOMIC NAME:

Brachiopoda

COMMENT on IDENTIFICATION:

of form

FOSSIL RECORD FORM

PLEASE TYPE OR PRINT CLEARLY

Circle appropriate options

Initials of master-file curator: _____

D44 /f 295
 NZMS260 Sheet serial number recolln.

If collection from Cutting
 drill-hole, state: Core depth m

GRID REFERENCE (NZ Map Grid):

Use only 3 digits unless from 1 986 133 748
 1:25000 (or larger scale) source map date easting northing

DATE OF COLLECTION: - 5 1 992
 day month year

COLLECTOR(s): S. MACCULLOCH, S. OWEN

LOCALITY: By the side of a new road cutting to the
 south of Roenix Gully.

LITHOSTRATIGRAPHIC NAME: MACLEAN PEAKS FAN, TAKITIMU GROUP.

FOSSILS IN PLACE? ☒ Yes Almost No Unknown

SENT TO (Macrofauna)-

UNIVERSITY OF OTAGO.

or HELD BY: (Microfauna)-

(Microflora)-

Other (specify)-

person

laboratory

OR NOT COLLECTED, but fossils seen (specify fossils):

SIGNIFICANCE OF SAMPLE, REMARKS:

Inferred stage PERMIAN Known stage limits Previous samples nearby /f

STRATIGRAPHIC RELATIONSHIPS:

below

below

m above

/f

m

above

/f

m below/above

: top/base of

rock unit

m below/above

: top/base of

rock unit

COLUMN or MAP, see:

dip W N E Normal
 S strike (true) Overturned

PREDOMINANT GRAIN SIZES:

6 9
 pri. sec.

GRAIN-SIZE COMPARATOR USED? Yes ☒ NoSTRATIFICATION (a) Bed thickness: ☒(b) Internal features ☐

B boulder 1 granule 4 medium sand 7 silt
 C cobble 2 very coarse sand 5 fine sand 9 mud
 P pebble 3 coarse sand 6 very fine sand 8 clay

1 non-bedded 4 5-60 cm G graded
 2 > 120 cm 5 1-5 cm S slump-folded
 3 60-120 cm 6 < 1 cm (laminated) X cross bedded

WEATHERING: ☒HARDNESS: ☒CARBONATE: ☒

COLOUR: M1312

Wet ☒ Dry

1 none or slight
 2 moderate
 3 intense

1 unconsolidated
 2 moderately soft
 3 moderately hard
 4 hard

1 non-calcareous
 2 calcareous
 3 limestone

L light 1 white 4 red 7 green
 M medium 2 grey 5 brown 8 blue
 D dark 3 black 6 yellow 9 purple

ADDITIONAL FEATURES (Feature present, one letter; abundant, two letters): Z P?

C carbonaceous M micaceous P pyritic Z sulphurous S shelly O concretionary Q highly quartzose
 G glauconitic F phosphatic T tuffaceous B bentonitic U burrowed R rock fragments X feldspathic

INFERRED ENVIRONMENT Marine/Non-Marine or specify: MARINE

NATURE OF ROCK UNIT:

Include any characteristic
 not already mentioned

CORRESPONDENCE, and CROSS-REFERENCES to other files:

S. MACCULLOCH BSc (Hons) Thesis 1992
 Nugget Hill.

STAGE

ADOPTED:

BY:

Geologist, from all available data

DATE

1 9

COLLECTOR'S

FIELD NO.: 7295

MANDATORY DATA for registration of form

STRATIGRAPHY

SEDIMENTARY FEATURES

FOSSIL RECORD NUMBER:

D44 / f 295

GROUP:

Atomodesmatinidea

IDENTIFIER:

S. MacCulloch

DATE:

- 9 1992

STAGE: COMMENT on STAGE DETERMINATION:

LAB. NUMBER: COMMENT on COLLECTION:

FORMAL TAXONOMIC NAME:

Trabeculata trabeculum

COMMENT on IDENTIFICATION:

FOSSIL RECORD FORM

PLEASE TYPE OR PRINT CLEARLY

Circle appropriate options

Initials of master-file curator: _____

D44 /f 294
NZMS260 Sheet serial number recolln.If collection from Cutting
drill-hole, state: Core depth m

GRID REFERENCE (NZ Map Grid):

Use only 3 digits unless from 1:25000 (or larger scale) source
map date easting northingDATE OF COLLECTION: 20 5 1992
day month year

COLLECTOR(s): S. MACCULLOCH, M. MOSS

LOCALITY: In a road cutting to the east of Nugget Hill,

LITHOSTRATIGRAPHIC NAME: MACLEAN PEAKS FMN., TAKITIMU GROUP.

FOSSILS IN PLACE? Yes Almost No Unknown

SENT TO (Macrofauna)-

or HELD BY: (Microfauna)-

(Microflora)-

Other (specify)-

person

laboratory

OR NOT COLLECTED, but fossils seen (specify fossils):

SIGNIFICANCE OF SAMPLE, REMARKS:

Inferred stage PERMIAN Known stage limits Previous samples nearby /f

STRATIGRAPHIC RELATIONSHIPS:

below

m

above

/f

below

m

above

/f

m below/above : top/base of rock unit

m below/above : top/base of rock unit

COLUMN or MAP, see:

steeply W N E Norm. Normal
dip strike (true) Overturned

PREDOMINANT GRAIN SIZES:

4 pri. sec.

GRAIN-SIZE COMPARATOR USED? 4 Yes No

STRATIFICATION

(a) Bed thickness: 1 2 3

(b) Internal features

B boulder

1 granule

4 medium sand

7 silt

9 mud

1 non-bedded

4 5-60 cm

G graded

C cobble

2 very coarse sand

5 fine sand

2 > 120 cm

5 1-5 cm

S slump-folded

P pebble

3 coarse sand

6 very fine sand

8 clay

3 60-120 cm

6 < 1 cm (laminated)

X cross bedded

WEATHERING: 1 2 3 4

HARDNESS: 1 2 3 4

CARBONATE: 1 2 3

COLOUR: 1 2 3 4 5 6 7 8 9

Wet Dry

1 none or slight
2 moderate
3 intense1 unconsolidated
2 moderately soft
3 moderately hard
4 hard1 non-calcareous
2 calcareous
3 limestoneL light
M medium
D dark1 white
2 grey
3 black4 red
5 brown
6 yellow7 green
8 blue
9 purple

ADDITIONAL FEATURES (Feature present, one letter; abundant, two letters): CTX

C carbonaceous

M micaceous

P pyritic

Z sulphurous

S shelly

O concretionary

Q highly quartzose

G glauconitic

F phosphatic

T tuffaceous

B bentonitic

U burrowed

R rock fragments

X feldspathic

INFERRED ENVIRONMENT Marine/Non-Marine or specify: MARINE

NATURE OF ROCK UNIT:

Include any characteristic not already mentioned

CORRESPONDENCE, and CROSS-REFERENCES to other files:

S. MACCULLOCH BSc(Hons) THESIS 1992
NUGGET HILL

STAGE

ADOPTED:

BY:

Geologist, from all available data

DATE

1992

COLLECTOR'S

FIELD NO.: STM 15.4

FOSSIL RECORD NUMBER: D44/f294

GROUP: MISCELLANEOUS. IDENTIFIER: H. J. CAMPBELL DATE: 9 1 992

STAGE: COMMENT on STAGE DETERMINATION:

LAB. NUMBER: COMMENT on COLLECTION:

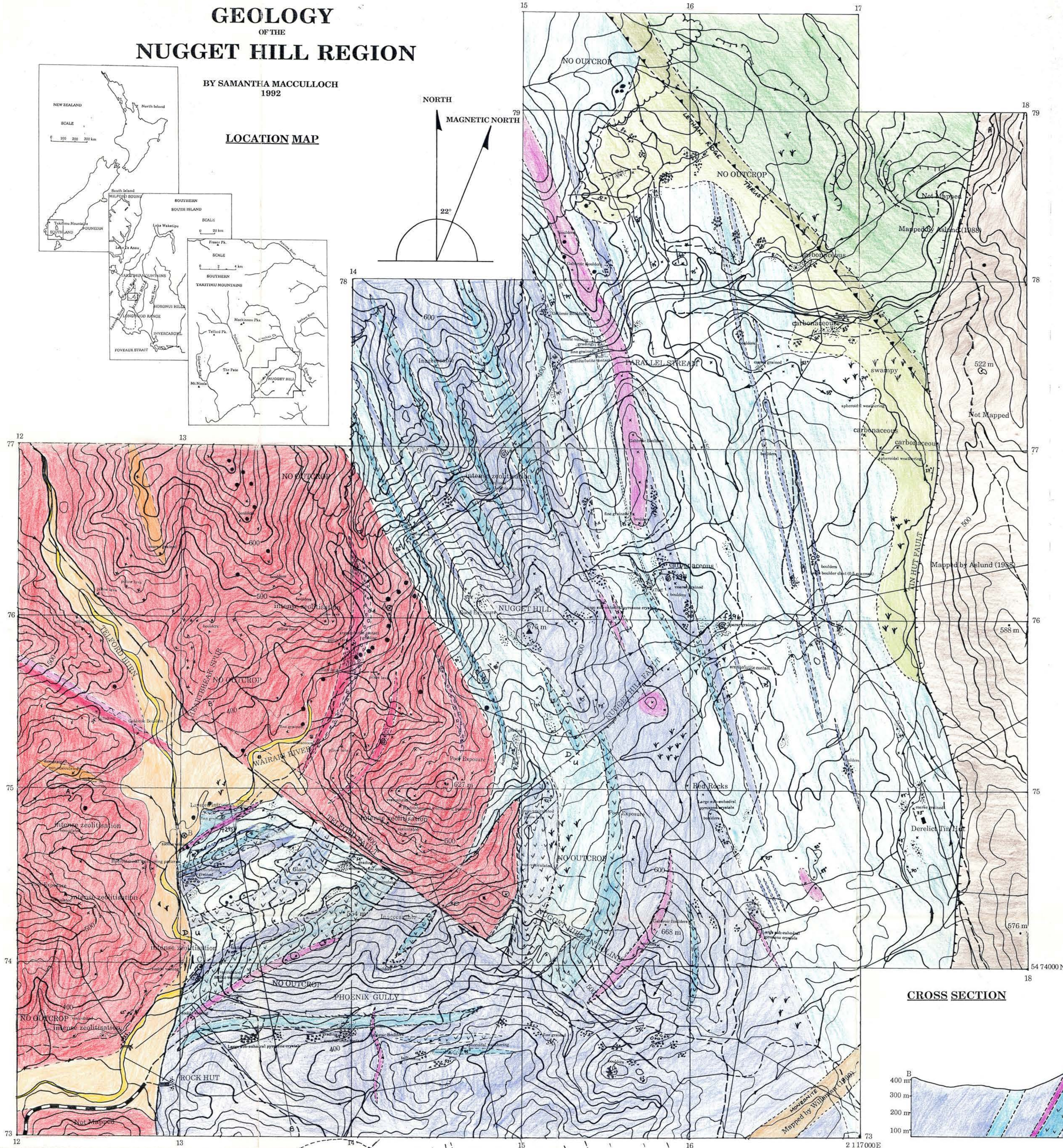
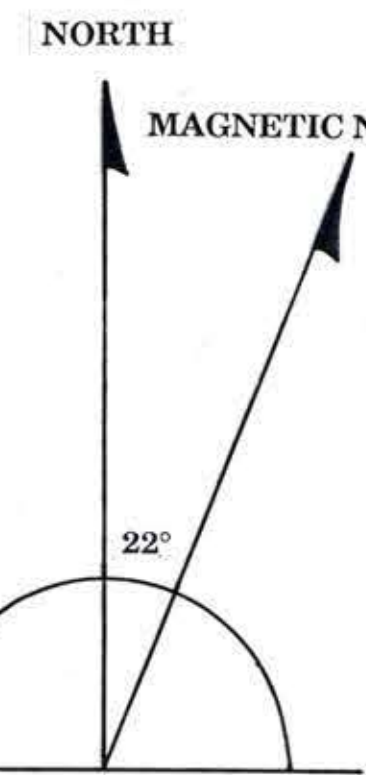
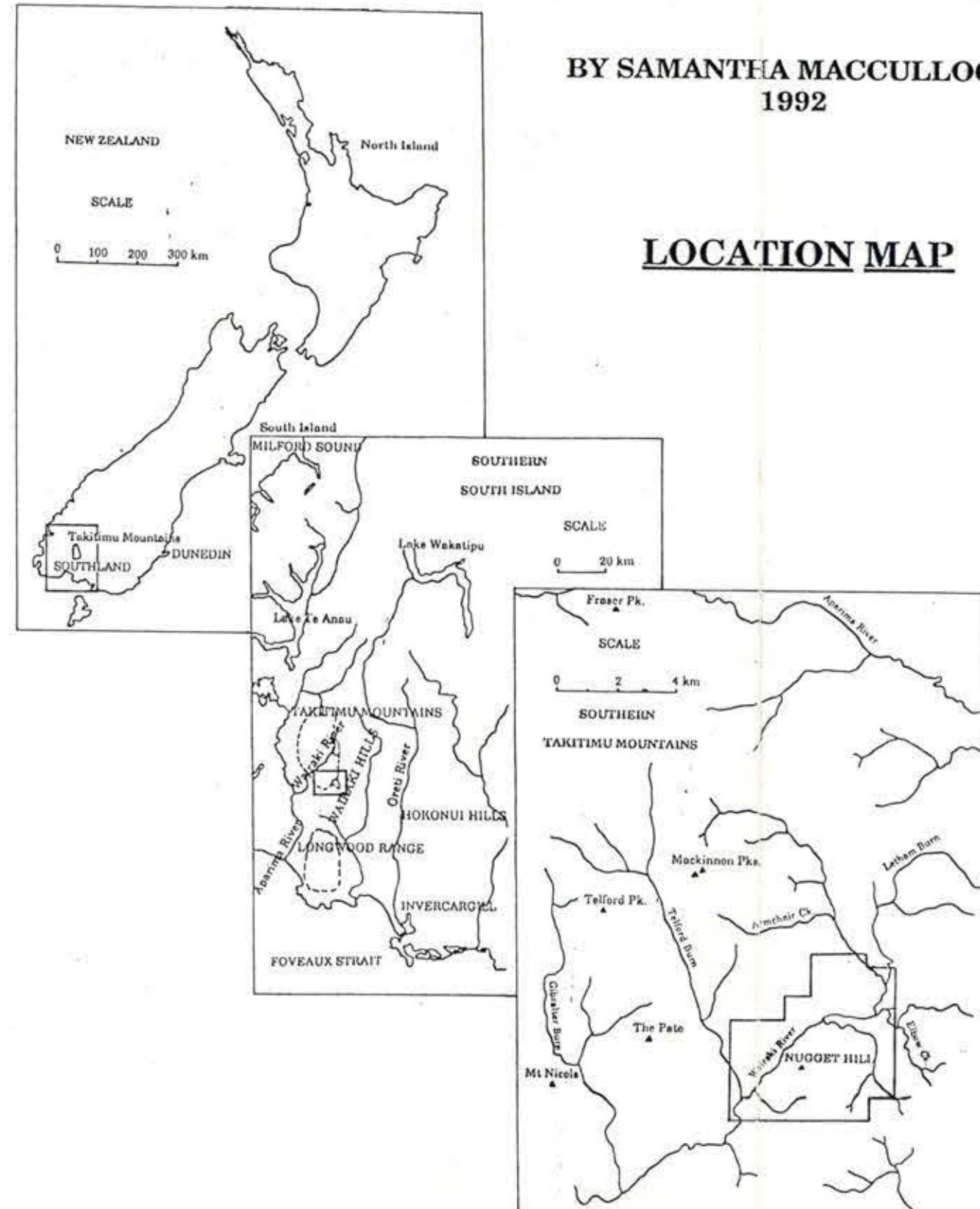
FORMAL TAXONOMIC NAME: COMMENT on IDENTIFICATION:

Cladochonus. sp.

GEOLOGY OF THE NUGGET HILL REGION

BY SAMANTHA MACCULLOCH
1992

LOCATION MAP



LEGEND

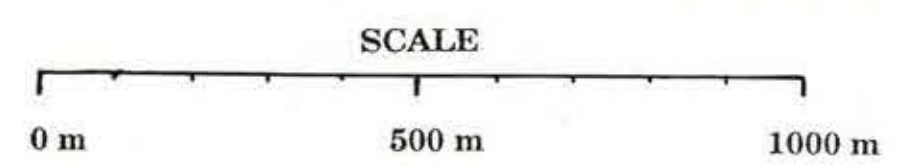
FORMATIONS	LITHOLOGICAL DESCRIPTIONS	AGE
ALLUVIUM	Recent river gravels and flood plain deposits.	Holocene
	River terrace gravels and alluvial fans.	Quaternary
WAIKAKI MELANGE	Wairaki Melange: veined, prominent knickers in a sheared siltstone matrix. Contains deformed Murihiku sediments and chalky white matrix due to the presence of laumontite.	
BARRETT'S FORMATION	Sandstone-conglomerate: very well rounded pebble-cobble-boulder conglomerates composed dominantly of granitic and alicic volcanic clasts. Fine-medium (angular)-coarse grained (rounded) carbonaceous sandstones consisting dominantly of quartz, plagioclase and K-feldspar.	Jurassic
MURIHIKU SUPERGROUP	Siltstone-sandstone: brownish-grey, very hard fine grained rock veined by siltite.	Middle Triassic
OLIVINE MONZONITE	Olivine Monzonite: 4 km long dyke trending N.E.-S.W. chilled margins contain large clusters of plagioclase phenocrysts which weather out to form 'birdsfoot' shaped pits on weathered surfaces.	Early Triassic
WHITE HILL INTRUSIVE SUITE	Gabbro and Microgabbro: discontinuous bodies sometimes occurring as dykes but usually as sills. Light grey, fresh, medium-coarse grained crystalline rocks.	Late Permian
TAKITIMU GROUP		
CARAVAN FORMATION	Pyroxene-rich basalts and two pyroxene andesites are abundant, with less abundant volcaniclastic material. Basalts are very mafic and contain large (2-5 mm) green pyroxenes.	Early Permian
MACLEAN PEAKS FORMATION	Volcanogenic arenite and lutite: dark grey blue to brown coloured, fine-coarse grained, angular feldspar and turbidite sequences with rare tuff beds, massive to localised grading, fossiliferous. Fossils include <i>Cladoceras</i> , <i>Attemaella</i> and <i>Attemaematinae</i> .	
	Volcanogenic rudites: dominantly submarine, clasts ranging from pebble to boulder sized. Sorting varies from moderately well sorted in the pebbly rudites to very poorly sorted in some of the coarser rudites. Basaltic-andesite and basaltic clasts in a sandy tuffaceous matrix.	
	Basaltic-andesite: subaerial flows to submarine pillow lavas, discontinuous bodies alternated with rudite, arenite and lutite.	
	Basalt: isolated discontinuous subaerial lava flows.	
HEARTBREAK FORMATION	Basaltic-andesite: submarine flows and pillow lavas, dark grey (fresh) to fleshy pink (zeolitized), contains abundant plagioclase phenocrysts.	Early Permian (Mangapirian)
	Basalt: dark grey, very fine-grained with plagioclase being the dominant phenocryst phase.	
	Volcanogenic flysch: grey-brown discontinuous lenses alternating fossiliferous lutite beds containing interbedded arenite. Fossil: <i>Attemaematinae</i> .	
	Volcanogenic rudite: sub-angular to well rounded basaltic-andesite clasts set in a sandy tuffaceous matrix.	

GEOLOGICAL SYMBOLS

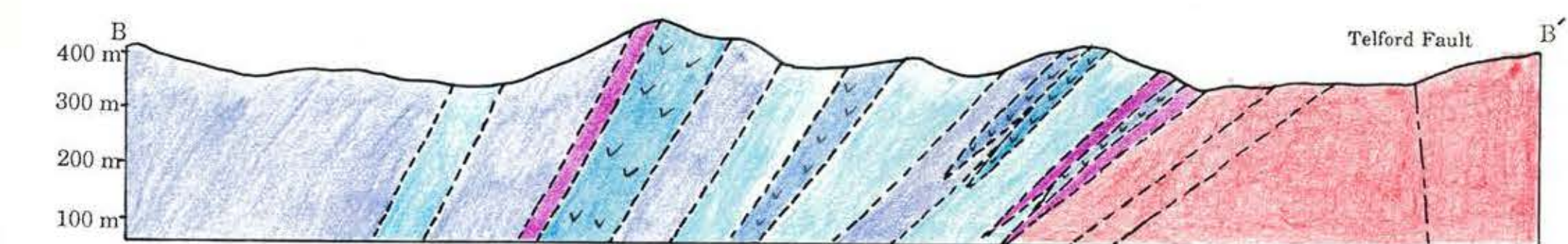
✱	Outcrop	~~~~~	Tuff
↘ 70°	Bedding, Strike/Dip (Not Overturned)	~~~~~	Lutite
↘ 75°	Overturned Bedding	~~~~~	Arenite
80°	Shear Zone	~~~~~	Pebbly Rudite
↘ 25°	Slickensides	~~~~~	Cobbly Rudite
⊙	Fossil Locality	~~~~~	Bouldery Rudite
✱	Inferred Antiform	B ⊙	River Sand Samples
Geological Contacts			
Located Accurately Located Approximately Inferred			
Fault, ticks on the upthrown side. Located Inferred			

TOPOGRAPHIC REFERENCE

—	Fence Line	~~~~~	River
—	Gravel Road	~~~~~	Stream
---	4-Wheel Drive Track	▲	Trig Station
—	Footbridge (fb)	522 m	Elevation, in metres
500	Index Contours	~~~~~	Native Beech Forest
Intermediate Contours (20 m Contour Interval)		●	Trees
Escarpment		■	Hut
Swamp			



CROSS SECTION



CROSS SECTION

